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Automobile Emission Control-The Development Status, Trends, and Outlook as of December 1976

a report to
the Administrator,
Environmental Protection Agency

prepared by
Emission Control Technology Division,
Mobile Source Air Pollution Control,
Office of Air and Waste Management,
Environmental Protection Agency

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This report is sixth in a series of reports on automobile control technology and is based on information submitted to EPA from automobile manufacturers during the time period of December 1976 through February 1977. The report contains conclusions about emission standards and the years in which they could be implemented, the relationship between fuel economy and emission control, the potential differences in emission control technology at different emission levels, the possible impact of MMT, unregulated emissions of concern, the impact of a non-methane hydrocarbon standard, and the rate of progress in the emission control area. Significant development trends are highlighted in the following areas: 3-way catalysts; improved fuel metering; electronic controls; non-catalytic emission control technology; vehicle space requirements for emission controls; turbocharging; and diesel engine developments. A review of each manufacturer's emission control development efforts is included.

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Table of Contents

1. Introduction 1-1

2. Conclusions 2-1

   2.1. Conclusions 2-1
   2.2. Discussion of Conclusions 2-5

3. Development Trends 3-1

   3.1. Emission Control Systems Containing 3-Way Catalysts Are Receiving the Most Effort 3-1
   3.2. Improved Fuel Metering Systems Continue to Receive High Emphasis 3-7
   3.3. Significant Use of Electronic Controls Appears to be a Relative Certainty in the Next Few Years 3-9
   3.4. Non-Catalytic Engine and Emission Control Technology is Also Showing Some Interesting Developments 3-11
   3.5. Catalytic Developments Other Than the 3-Way Catalyst Are Also of Interest 3-13
   3.6. There Are Indications That The Space Required For Emission Control Systems May Become A Future Problem 3-14
   3.7. Turbocharging as a Means to Increase Vehicle Performance Is an Active Area 3-14
   3.8. Diesel Engine Development Continues to Receive Emphasis - But the Development Work on the Diesel's Problem Areas Does Not Seem to be Receiving the Intensive Effort Which May be Necessary to Meet Stringent Emission Standards 3-15
   3.9. The Efficiency at Which Development Information on Emissions Related Subjects Is Reported to EPA May Be Decreasing 3-18

4. Fuel Economy And Cost 4-1

   4.1. Fuel Economy 4-1
   4.2. Cost 4-31

5. Driveability 5-1

Table of Contents (con't)

6. Unregulated Emissions 6-1

6.1. Sulfuric Acid 6-1
6.2. Hydrogen Cyanide (HCN) 6-27
6.3. Ruthenium Emissions 6-38
6.4. Ammonia 6-40
6.5. Polynuclear Aromatic Compounds (PNA) 6-44
6.6. Diesel Particulate Emissions 6-53

7. Individual Manufacturer Reviews 7-1

7.1.1. American Motors (AMC) 7-1
7.1.2. Chrysler 7-27
7.1.3. Ford 7-52
7.1.4. General Motors (GM) 7-94

7.2. Independent Developers 7-150

7.2.1. Bendix 7-150
7.2.2. Robert Bosch 7-160
7.2.3. Dresser 7-176
7.2.4. Engelhard 7-182
7.2.5. Ethyl 7-198
7.2.6. Holley 7-204
7.2.7. Matthey Bishop 7-210
7.2.8. Questor 7-217
7.2.9. Universal Oil Products (UOP) 7-223
7.2.10. Walker 7-226

7.3. Foreign Manufacturers 7-235

7.3.1. BMW 7-235
7.3.2. British Leyland 7-241
7.3.3. Citroën 7-255
7.3.4. Daimler-Benz 7-257
7.3.5. Fiat 7-281
7.3.6. Fuji Heavy Industries (Subaru) 7-286
7.3.7. Honda 7-289
7.3.8. Mitsubishi 7-295
7.3.9. Nissan (Datsun) 7-309
7.3.10. Peugeot 7-330
7.3.11. Renault 7-335
7.3.12. Rolls-Royce 7-341
7.3.13. Saab 7-347
7.3.14. Toyo Kogyo (Mazda) 7-363
7.3.15. Toyota 7-368
7.3.16. Volkswagen (VW) 7-404
7.3.17. Volvo 7-432

Appendix 1 . . . . A1-1

SECTION 1

INTRODUCTION

This report is a summary of the current technical status and development trends in the automobile emission control field. This report has been prepared for the Administrator of the U.S. Environmental Protection Agency (EPA) to inform the Administrator and other interested parties of the current status in the emission control technology area.

This report contains a summary and evaluation of the development programs of automobile manufacturers and other organizations involved in the development of automobile emission control technology.

This report does not contain projections of future air quality, analysis of future air quality requirements, or any other air quality studies. A detailed discussion of these topics is available in the literature.*

The period of time of interest for this report is the 1978 model year and post-1978 (1979-1985) time period. This time period is considered as a range related to the current deliberations by Congress on the Clean Air Act.

Most of the information in this report came from manufacturers' responses to a request from EPA. Most of the responses from the manufacturers were received during December 1976 to February 1977, so the information pertains to the period of time around the end of calendar year 1976. The specification of time to which the data relate is important in an area like emission control technology, in which progress is continually being made.

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* Air Quality, Noise and Health, Report of a Panel of the Interagency Task Force on Motor Vehicle Goals Beyond 1980, March 1976.

Copies of the responses submitted by the manufacturers are available for public inspection at the EPA Freedom of Information Center at the EPA Headquarters Building, 401 M. Street, S.W., Washington, D.C. A copy of the letter request from EPA and the date of receipt of the responses are included in Appendix 1.

Other data used in the preparation of this report were: a) 1976 and 1977 certification results, b) 1978 Part I applications for certification, and c) the technical literature.

This report is the sixth in a series of reports on the same subject. The earlier reports were:

Automobile Emission Control - A Technology Assessment as of December 1971.
Automobile Emission Control - The State of the Art as of December 1972.
Automobile Emission Control - The Development Status as of April 1974.
Automobile Emission Control - The Technical Status and Outlook as of December 1974.
Automobile Emission Control - The Current Status and Development Trends as of March 1976.

The nomenclature used in this report for emission test results and standards is a triplet abbreviation. In this shorthand notation for example, the 1975 Federal standards of 1.5 grams per mile hydrocarbons, 15 grams per mile carbon monoxide and 3.1 grams per mile oxides of nitrogen are abbreviated 1.5 HC, 15 CO, 3.1 NOx with the understanding that the dimensions are grams per mile. Similarly, a vehicle that achieved 0.2 grams per mile hydrocarbons, 2.2 grams per mile carbon monoxide and 0.22 grams per mile oxides of nitrogen on a given test would be said to achieve the levels of 0.2 HC, 2.2 CO, 0.22 NOx.

The current emissions standards are thus:

1977 California: 0.41 HC, 9 CO, 1.5 NOx
1977 Federal: 1.5 HC, 15 CO, 2.0 NOx
1978 50-state: 0.41 HC, 3.4 CO, 0.4 NOx

When urban, highway, and composite fuel economy data are available, they are added after the triplet notation as MPG_u, MPG_h, and MPG_c respectively.

A specific note on nomenclature should be mentioned here. This report uses both the nomenclature "dual catalyst" and "3-way plus oxidation catalyst" (3-way + ox cat), to describe certain types of emission control systems.

Both systems use two types of catalysts in series. The dual catalyst system has historically been one in which the first catalyst has been optimized for control of NOx. The 3-way plus oxidation catalyst system has been one in which the oxidation catalyst has been added to the system in order to oxidize HC and CO that otherwise might be in excess of the standards. This is especially the case for CO with 3-way catalysts.

The way that the systems operate during the emission test and recent developments have caused the distinction between the two systems to become less clear.

Because the NOx catalyst and the 3-way catalyst both are the catalysts closest to the engine, it is preferable to use them as oxidation catalysts during the cold start portion of the test to hasten catalyst warm-up. Therefore, HC and CO conversion efficiency and catalyst stability under oxidizing conditions are important for NOx catalysts as well as 3-way catalysts. Secondly, the desire to reduce ammonia emissions and the need to optimize for fuel economy has led to a requirement for more precise fuel metering for dual catalyst systems. This point also adds to the similarity of dual catalyst and 3-way catalyst systems because 3-way catalyst systems also require precise fuel metering.

Therefore, because of the start-up system requirements, and the fuel metering requirements, it might be said that there is little difference between the two system types, and they could be combined into one. However, for the purpose of this report the distinction is made. Three-way plus oxidation catalyst systems typically have a platinum/rhodium composition and could potentially be a candidate system without the oxidation catalyst at low HC and CO levels. Dual catalyst systems can have a variety of compositions for the NOx catalyst including base metals. Because the dual catalyst calibration of air-fuel ratio is generally richer than stoichiometry and thus the NOx catalyst does not oxidize HC and CO after warm-up, the NOx catalyst alone is not effective in controlling HC and CO emissions to the required levels.

In time, the differences may vanish altogether, as development continues and the systems with superior performance are more clearly identified.

SECTION 2

CONCLUSIONS

2.1 Conclusions

Based on a review of the available data, EPA technical staff have reached the conclusions listed and discussed below. The conclusions apply to the time period (Spring 1977) in which they are made. In the field of emission control technology, rapid changes in progress can occur. These technical changes can be positive, i.e., anticipated improvements may be achieved and even surpassed. These changes can also be negative, i.e., concepts that had shown promise in initial testing or on a theoretical basis may prove out to be less attractive when examined in more detail. Additionally, new developments may arise which can cause changes in the direction or emphasis of development programs and a possible dilution of the effort targeted toward demonstrating compliance with future emissions standards. Examples of developments that have occurred or are occurring are: (1) legislative imperatives such as the fuel economy standards of the Energy Policy and Conservation Act (EPCA), and (2) technological issues, such as the effects of the gasoline additive MMT on emission controls. Therefore, the conclusions listed below may need to be altered if changes in progress occur or if new developments arise.

Conclusion 1

The currently applicable standards for model year 1978, 0.41 HC, 3.4 CO, 0.4 NOx, cannot be met for model year 1978.

Conclusion 2

The issue of when more stringent emission standards can be met was specifically addressed in this report. The following table lists emission standards and the model year in which they can be met, based on the following assumptions:

1. Emission control is the single constraint. Fuel economy, cost, performance, driveability and other considerations find their own levels.
2. The automobile industry knows what the standard will be by June 1977.
3. Market demand must be met.
4. All effort is directed toward attainment of a single standard. Additional requirements to meet other standards in preceding or succeeding model years can dilute the industry's effort and could change the estimated dates shown below. This means that the table should not be interpreted as a set of emission standards versus time, it simply indicates the earliest dates at which the standards are expected to be achievable.
5. All 0.41 HC standards assume a methane exclusion.

Emission Standard	Earliest Model Year
0.41 HC, 9 CO, 1.5 NOx	1979
0.41 HC, 3.4 CO, 2.0 NOx	1979*/1980
0.41 HC, 3.4 CO, 1.0 NOx	1981
0.41 HC, 3.4 CO, 0.4 NOx	1982

* With a delay in the introduction of new models.

Conclusion 2

The fuel economy performance of a vehicle at any emission level is strongly influenced by the type of technology used to control emissions. Emission control technology, better than today's emission control technology, has been and is being developed by the automobile industry. Use of such improved emission control technology, given the time to optimize the systems for both fuel economy and emissions, can result in the attainment of future emission standards with no adverse impact on fuel economy. Use of improved emission control technology in conjunction with other technological changes planned by the automobile industry to improve fuel economy can result in significant improvements in sales weighted fuel economy of future model year fleets over the 1977 model year fleet.

Conclusion 4

With the technical approaches now under consideration, there is a significant difference between systems targeted toward 3.4 CO and those targeted toward 9 CO.

Conclusion 5

The octane improver fuel additive, MMT, is beginning to appear in motor vehicle fuels in significant concentrations. While there is considerable uncertainty over its impact on catalytic emission control systems, there is sufficient cause for concern over reports of deterioration of engine-out hydrocarbon emissions and catalyst plugging. The manufacturers are especially concerned about impacts upon the emission control systems targeted for the statutory HC level.

Conclusion 6

The study of emissions of currently unregulated substances continues to be an active area of investigation. New areas of potential emissions have been identified, specifically, transition metals and rare earth elements that are used to promote the emissions performance of catalyst systems.

Conclusion 7

The adoption of a non-methane hydrocarbon (NMHC) standard, equivalent in stringency for reactive hydrocarbons to the statutory total hydrocarbon standard of 0.41, has the potential impact of increasing the industry's capability to comply at this level. Methane is non-reactive and thus difficult to control with catalytic technology. A NMHC standard also has potential fuel economy, system complexity, and cost benefits, depending on the actions taken by the industry.

Conclusion 8

The rate of progress in the development of emission control systems to meet future, more stringent emission standards appears to be at about the same rather slow pace that was evident last year. Some changes in emphasis have occurred, however.

2.2 Discussion of Conclusions

Discussion of Conclusion 1

Virtually all automobile manufacturers are planning to meet emission standards of 1.5 HC, 15 CO, 2.0 NOx for model year 1978. These emission standards are the same as the emission standards for model year 1977. In their responses to EPA, most of the automobile manufacturers indicated that their plans for model year 1978 were based on the 1976 Conference Committee Report on amendments to the Clean Air Act. That report had emission standards for model year 1978 of 1.5 HC, 15 CO, 2.0 NOx. Even though the changes to the Clean Air Act contained in that Report were subsequently not adopted by Congress, the manufacturers' position appears to be that the intent of Congress was to adopt emission standards of 1.5 HC, 15 CO, 2.0 NOx for model year 1978, thus they have based their plans accordingly.

Because the plans of the manufacturers are targeted toward meeting 1.5 HC, 15 CO, 2.0 NOx for model year 1978, there is little possibility that emission standards much different from these levels could be successfully implemented for model year 1978. Even for a relatively lenient standard like 0.9 HC, 9 CO, 2.0 NOx, for example, some durability vehicles would have to be rerun, calibration and system modifications for each data vehicle would have to be reexamined and possibly redeveloped, new or additional supplies of certain components might be required which are not now planned for. All of this leads to the conclusion that there is not now enough lead time to do anything significantly different from what the manufacturers are already planning to do for model year 1978.

Discussion of Conclusion 2

Estimation of the earliest dates that more stringent emission standards could be achieved from a purely emission control technology standpoint is provided in the table below. While such estimates are important they are of limited value since the automobile industry is faced with other important considerations, the principal one being fuel economy. A discussion of each of the standards considered follows:

Emission Standard	Earliest Model Year
0.41 HC, 9 CO, 1.5 NOx	1979
0.41 HC, 3.4 CO, 2.0 NOx	1979*/1980
0.41 HC, 3.4 CO, 1.0 NOx	1981
0.41 HC, 3.4 CO, 0.4 NOx	1982

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* With a delay in the introduction of new models.

0.9 HC, 9 CO, 2.0 NOx

The 0.9 HC, 9 CO, 2.0 NOx standards could be met in 1979 with good fuel economy, but considering the desirability of having standards in force for at least two years, the optimization of technology at this lenient emission level could slow the development of improved technology, especially 3-way catalysts. However, considering the fact that MMT will be used in the certification durability fuel for the first time in 1979 there would be less technical risk at this level than for more stringent HC standards in that year.

0.41 HC, 9 CO, 1.5 NOx

These standards are numerically the same as the standards for California for model year 1977. While extension of technology developed for California to Federal application might seem at first to be relatively straightforward, there are differences between California and Federal certification protocols that complicate the issue somewhat. The most important difference is that for model year 1977 California permitted a durability vehicle to line cross.* That is, the straight line fit to the data may exceed the emission standard anytime during the 50,000 miles of durability mileage accumulation as long as the emission data vehicle's emissions, projected to 50,000 miles do not exceed the standards. For Federal protocols, line crossing of the durability vehicle is not permitted. This difference has important implications because of the ability to meet stringent emission standards depends almost totally on the ability of vehicles to have good emission performance at high mileage. In fact, maintaining emissions below the standards for 50,000 miles has been the most difficult task industry has faced in meeting stringent emission standards since the 1970 Clean Air Act amendments were passed. Therefore, the California experience is not directly translative into projections of compliance with Federal emission standards that are numerically the same.

At emission levels of 0.41 HC, 9 CO, 1.5 NOx, the pollutant presenting the most difficulty is HC. It is a long way from 1.5 HC to 0.41 HC as far as control technology and the difficulty of compliance are concerned. This is especially true when the relationship between HC emissions and fuel economy is considered. If the emission control system does not have the capability to control HC adequately when spark timing is set for good fuel economy, compromises may have to be made in spark timing calibrations (more retard) that can adversely affect fuel economy.

Time and effort are required to develop emission control systems to meet 0.41 HC while retaining good fuel economy calibrations. This is borne out by the experience in California where fuel economy of the California fleet has lagged the Federal fleet (on a equal model mix basis) by 1-2 years largely as a result of the less than optimum systems and calibrations used to meet the more stringent California standards. This extra time is a consideration that leads to an implicaton that the 1980-1981, rather than 1979, time frame may be a more attractive date for the application of these standards of 0.41 HC, 9 CO, 1.5 NOx.

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* California allowed line crossing to avoid the need to require manufacturers to run a separate durability vehicle for each engine family to be sold in California. Thus 1977 California vehicles are in most cases simply recalibrated 49-state vehicles. California has advised EPA (letter dated 2 February 1977 from Thomas C. Austin, Deputy Executive Officer-Technical CARB to Benjamin Jackson, Director Mobile Source Enforcement Division) that it does not recommend allowing line crossing for 49-state vehicles.

The adoption of a non-methane hydrocarbon (NMHC) standard would make the compliance task at 0.41 HC less difficult. However, the effect is small compared to the reduction required from current Federal standards.

The 0.41 HC, 9 CO, 1.5 NOx standards would tend to encourage the development and introduction of 3-way catalyst systems if these levels are followed in succeeding model years by lower NOx standards. This is considered important, since many of the systems that will be used to meet emission standards more stringent than 0.41 HC, 9 CO, 1.5 NOx will contain 3-way catalysts, and the 0.41 HC, 9 CO, 1.5 NOx standards permit the phase-in of this type of technology.

0.41 HC, 3.4 CO, 2.0 NOx

While these standards could be met in the 1979-1980 time period, they might not result in an orderly phase-in of 3-way catalyst technology. The 3.4 CO level will be difficult to meet with 3-way catalyst systems in the near term, and the 2.0 NOx level offers no real incentive to use the 3-way catalyst for NOx control. The systems used to meet the 0.41 HC, 3.4 CO, 2.0 NOx standards would more likely be advanced oxidation catalyst systems. These systems would be similar to current Federal systems but would utilize larger, more efficient oxidation catalysts and some form of air injection. If standards more stringent than 0.41 HC, 3.4 CO, 2.0 NOx are eventually going to be required, and assuming systems using 3-way catalysts will be used to meet these more stringent standards, then it would appear that the 0.41 HC, 3.4 CO, 2.0 NOx standards would not encourage the phase-in of the types of technology that will eventually be needed.

0.41 HC, 3.4 CO, 1.0 NOx

These standards could be met in 1981. However, as was the case for 0.41 HC, 9 CO, 1.5 NOx, more time may be required for the development by all manufacturers of systems that meet these standards with good fuel economy. The standards of 0.41 HC, 3.4 CO, 1.0 NOx could more reasonably be met* in 1982-1983, following two years (1980-1981) at 0.41 HC, 9 CO, 1.5 NOx. Two years is considered the minimum number of years that emission standards should remain constant. This gives manufacturers time to optimize the systems, because the standards are not continually changing, without excessively stretching out the time for getting to more stringent standards.

The most difficult pollutant to control at the 0.41 HC, 3.4 CO, 1.0 NOx level will be CO, if 3-way catalyst systems are used. The addition of a downstream oxidation catalyst and air injection might be required on some vehicles. A CO standard somewhere between 6 and 9 grams per mile could preclude the need for an oxidation catalyst and air injection and would make the compliance task easier for 3-way catalyst systems in this time period.

0.41 HC, 3.4 CO, 0.4 NOx

Following the same rationale as discussed above, the timetable for introduction of the 0.41 HC, 3.4 CO, 0.4 NOx standards could be 1984,* even though these standards could be met as early as 1982. This would permit more time for the development of the necessary technology that would also incorporate good fuel economy calibrations. One of the more important pacing items for this standard is the lead time necessary to develop and adopt the sophisticated fuel metering systems that may be required. Feedback carburetion may not be good enough, and fuel injection systems of some type may be needed. Additional time would also permit further optimization of catalyst performance.

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* This comment applies to the two smaller U.S. manufacturers and especially to car lines that may not have been downsized (well under 10% of the national market). It considers only the issue of optimal engineering phasing for these particular cars, and not health, costs, and other factors.

Discussion of Conclusion 3

A vehicle can be designed with emission control technology that will have poor fuel economy at a given emission standard if the control technology relies on non-optimal engine calibrations or is short of emission control capability. To compensate for the shortcoming in emission control capability, engine calibrations may have to be set so as to reduce emissions in a manner that compromises fuel economy, and fuel economy penalties can result.

However, if the emission control system has excess capability to control emissions, the use of engine calibrations that provide good fuel economy performance is feasible and emission standards can be met with no fuel economy penalty. In model year 1975, for example, the use of new emission control technology (i.e. catalysts) allowed better fuel economy calibrations to be used on the engine. This permitted fuel economy gains over model year 1974, even though the emission standards for model 1975 were substantially more stringent than those for model year 1974.

However, the use of even the best emission control technology does not guarantee good fuel economy, since fuel economy is determined principally by certain basic engine calibrations. If these basic engine calibrations deviate from the good fuel economy calibrations, fuel economy losses can result, regardless of the emission control technology used. The calibrations that result in good fuel economy for a given engine are a complicated combination of, for example, spark timing, air-fuel ratio, and EGR rate as a function of engine speed and load. Much experimental work is now underway to determine these calibrations for the engines planned for use in future model years. Considering the three calibration variables of spark timing, air-fuel ratio, and EGR rate, it appears that a good fuel economy calibration can be obtained over a range of air-fuel ratios. However, if EGR is not used, the air-fuel ratio calibration for good fuel economy is known to be slightly lean of stoichiometry.

This means that if an engine is operated at the stoichiometric air-fuel ratio, without EGR, as could be the case for a 3-way catalyst emission control system, a fuel economy loss would result when compared to slightly lean operation without EGR. Even though the emission control might be satisfactory without EGR, the desire to obtain good fuel economy calibrations might require the use of EGR and concomitant spark timing recalibration. This could tend to improve the NOx control while making HC control more difficult.

This sensitivity of fuel economy to engine calibrations and the still-evolving understanding of the interrelationships among the calibration variables often lead to a wide divergence of technical opinion about the fuel economy potential of a new emission control technology. This is particularly true during the early stages of development when emphasis is placed on determining the emission performance.

Historically, new emission control systems have improved in fuel economy over the years as more experience has been gained in system optimization. The improvement in fuel economy of the 1976 models over the 1975 models was to some degree due to the continued optimization of engine calibrations. Further, the fuel economy penalties apparent at the more stringent California emission standards is an illustration of compromises in engine calibration when an emission control system (e.g. the oxidation catalyst) approaches its limit of control capability.

In order to meet future, more stringent emission standards while retaining good fuel economy calibrations, emission control systems will have to be used that have improved emission control capability over systems currently in production. These improved systems will lead emission control capability beyond that just required to meet the emission standards. Such improved systems are now being developed by the automobile industry.

The status of the development of these systems is, of course, the subject of this report.

The development of technology to control emissions and permit good fuel economy calibrations to be maintained is expected to take longer than just the development of technology solely for the purpose of controlling emissions. For example, the use of electronic controls which have the potential to be an important part of future low emission, fuel efficient systems will require the generation and analysis of significant quantities of new engine data in order to determine more optimal calibrations.

Certain automobile manufacturers have indicated that, given time, future emission standards as stringent as 0.41 HC, 3.4 CO, 1.0 NOx can be met with little or no loss in fuel economy. Other manufacturers, however, maintain that fuel economy penalties will exist at these emission levels. Although the capability to meet the statutory emission standards (0.41 HC, 3.4 CO, 0.4 NOx) while retaining good fuel economy calibrations is also possible, little data have been reported with complete, improved emission control systems targeted toward these standards. The reason for this lack of data may be that 0.4 NOx may not have been considered to be a real target.

The impact of future emission standards on fuel economy should also be considered in relationship to other technological approaches for improving fuel economy. Taken in combination, reduced vehicle weight, improved rolling resistance, lower friction, drivetrain improvements, improved accessory drives, improved aerodynamics, and vehicle power-to-weight ratio changes can have a much larger impact on fuel economy than the fuel economy penalties reported by some as being due to emission control.

Discussion of Conclusion 4

Several manufacturers called for an ultimate CO standard higher than 3.4 CO in their submissions to EPA, basing their remarks at least in part on their interpretations of the Air Quality Panel report* from the "Interagency Motor Vehicle Goals Study". It is not the purpose of this report to discuss air quality-related issues. However, it is appropriate to discuss the differences in technological approaches that might be used to meet the two different CO levels.

For this technical discussion HC standards of 0.41 and NOx standards of 1.0 or 0.4 are considered in conjunction with the CO values. The basic emission control system type that is considered to be the most representative of the systems to be utilized at these emission levels is the 3-way catalyst.

The 3-way catalyst system used to meet 3.4 CO will tend to be more complicated and costly than the basic 3-way catalyst system to meet 9 CO. It will need to have more cold-start CO control than the 9 CO system. It may require thermal reactors and/or a start catalyst and/or a supplementary oxidation catalyst with air injection which is switched between the exhaust ports and downstream of the main 3-way catalyst. Much improved chokes and/or special quick warm-up devices such as super EFE may also be needed. Achievement of good driveability at the 3.4 CO level may be more difficult than at 9 CO unless systems of the types described above are employed. If, because of cost or other considerations, driveability is sacrificed at 3.4 CO, in-use vehicles could be maladjusted in an attempt to improve driveability with possible losses of emission control capability. Current experience with in-use vehicles shows that substantial losses of emission control capability results from simple maladjustments although the actual causes for maladjustment are not well established. However, there is sufficient reason for concern that poor driveability may be a significant motivating factor.

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* Air Quality, Noise and Health, Report of a Panel of the Interagency Task Force on Motor Vehicle Goals Beyond 1980, March 1976.

Meeting 3.4 CO with a 3-way catalyst system will require improvements over current practice. Improvements in engine-out emissions and in high mileage catalyst efficiency are the most important. Improvements in these areas can be expected, but the magnitude of these improvements remains to be determined.

Another example of potential cost and/or complexity differences between 3.4 and 9 CO is related to control of sulfuric acid emissions. If large quantities of excess air are used to control CO to the 3.4 level in the downstream oxidation catalyst of a 3-way plus oxidation catalyst system, sulfuric acid emissions can be expected to increase. Controlling the sulfuric acid emissions, while retaining adequate CO control, might require a modulated air injection system which is expected to be more sophisticated than current air injection systems.

Discussion of Conclusion 5

EPA, the petroleum and additive industry, and the automobile manufacturers are actively studying MMT's effects on emission control systems. The data to date are somewhat scattered and contradictory. The automobile manufacturers are extremely concerned about MMT's effects on emission control systems and this concern was magnified when EPA decided to require the use of MMT in the certification fuel for 1979.

At the time this report was being prepared, no definitive conclusions regarding MMT's effects on emission control systems could be made. Therefore in order to proceed with this report, assumptions had to be made. As far as this report is concerned the possible deleterious effect of MMT on emission control systems has been ignored. The conclusions and discussions in this report are based on this assumption: If MMT has a significant deleterious effect on emission control systems many of the conclusions of this report will need to be changed.

A conclusion that can be drawn about MMT, however, is that the technical effort that is required to properly assess the effects of MMT on emission control systems can only dilute the automobile industry's efforts to develop and evaluate future emission control systems. Also, any research and development effort to adapt or redesign emission control systems to account for MMT will have additional negative impacts on the rate of progress in the development of emission control technology.

Discussion of Conclusion 6

EPA has been interested in several currently unregulated emissions, among which are: (1) sulfuric acid, (2) particulates, (3) ruthenium, (4) hydrogen cyanide, (5) polynuclear aromatic hydrocarbons, and (6) dimethylnitrosoamines. An update of the status of the investigation of some of these substances can be found in Section 6.

For systems considered for future use, two additional categories of unregulated emissions have been identified. Both arise from the potential use of 3-way catalysts.

The first category deals with ammonia (NH_3) emissions. Like most systems that control NOx catalytically, 3-way catalysts can produce NH_3. Ammonia production has long been a concern with dual catalyst systems since the NH_3 can be oxidized back to NO over the oxidation catalyst thus reducing the total system conversion efficiency for NOx. With a 3-way catalyst system this difference between gross and net efficiency is important when there is a downstream oxidation catalyst to provide further control of HC and CO. Limited data suggest that ammonia can form a large family of ammonium salts (e.g. sulfates, nitrates) and could also be a precursor of nitrites and nitrates. It is also present as a common atmospheric component arising from both natural sources (decay of vegetation, soil bacteria) and man-made sources (fertilizers). The degree to which ammonia emissions from automobiles is considered to be a health concern is an open question. No definitive answers have as yet been generated, thus more work may be required in this area.*

Another potential category of unregulated emissions from 3-way catalysts has to do with the catalyst composition. Many ingredients are used, or are being considered for use, in 3-way catalysts beside platinum (Pt) and rhodium (Rh). Each ingredient is used to improve catalyst efficiency, widen the window of 3-way operation, and promote special chemical reactions such as the water-gas shift and steam reforming reactions. Unfortunately, the identity and amounts of these special materials are considered proprietary by manufacturers and are not generally available to EPA. These materials may be present in the catalyst in quantities significantly in excess of the quantities of noble metals. Some of these materials could be oxides of transition metals such as nickel, iron, cobalt, copper, chrome, cerium, and other rare earth metals. Also, lanthanum, barium, and magnesium might be present in the washcoat. The attrition byproducts of these materials (if any) and/or any potentially undesirable by-products of the desired and undesired chemical reactions catalyzed by these ingredients are not known to EPA at present. Although this discussion has concentrated on 3-way catalysts, it is possible that some of these concerns are also applicable to other catalysts.

Discussion of Conclusion 7

The National Ambient Air Quality Standard for hydrocarbons specifically excludes methane (CH_4). Until the advent of catalytic emission controls, however, it was not considered important to switch automotive HC measurement to a non-methane basis since it would have been simply a numerical exercise having minimal impact on either air quality or emission controls. The introduction of catalytic converters and the development of necessary instrumentation has changed this consideration significantly. There is general agreement that vehicles that made up the baseline from which the statutory 0.41 total HC (THC) standard was determined had about 5 per cent CH_4 in the exhaust. Therefore, the equivalent NMHC standard would be approximately 0.39 grams per mile.

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* Ammonia emissions do not seem to be significant. See pages 6-40 through 6-43 for a discussion.

EPA is considering proposed rulemaking that could permit the exclusion of methane from the determination of HC in automobile exhaust. This rulemaking would permit the manufacturers the option of certifying at 0.41 THC or 0.39 NMHC, both of which are equivalent to a 90% reduction of HC as required by the statutory HC standard. The earliest that NMHC testing could be performed by EPA is for Model Year 1979 certification.

Not all future emission control systems are affected in the same way by a NMHC standard. Since the engine-out exhaust methane fraction appears to remain at about a constant 5% even with emission control achieved by extensive engine modification, the NMHC standard will have little if any impact on non-catalyst technologies. Manufacturers using non-catalyst technology can choose to certify to either standard, the decision affecting only the instrumentation they choose to use on the Federal Test Procedure. On the other hand, systems that employ catalysts (probably the vast majority at a 0.39 NMHC standard) would benefit from a NMHC standard. This is because catalysts tend to preferentially oxidize the more reactive HC species and generally have a difficult time oxidizing less reactive HC species such as CH_4. Therefore, the methane mass fraction of the HC in the tailpipe of a catalyst-equipped vehicle is higher than the engine- out mass fraction. This means that with a total hydrocarbon standard of 0.41 the catalyst system must control the non-methane HC emissions considerably more than would be required for the 0.39 NMHC standard.

The exact CH_4 fraction is dependent on the details of the specific catalyst system. If it is assumed that the 0.39 NMHC standard is roughly equivalent to a 0.50 THC standard for a catalyst equipped vehicle, then the possibility exists that some important benefits could be associated with a NMHC standard. Possibly the most important benefit is in fuel economy. For a given vehicle, if the capabilities of the aftertreatment system are not adequate to reduce total HC to the desired level, calibrations in spark timing that have a deleterious effect on fuel economy may have to be used. Alternatively a change to a more costly and complex emission control system that has more control capability may be required. If a given vehicle/control system/calibration is close to the required HC level on a THC basis with a good fuel economy calibration, the change from THC to NMHC could allow the vehicle to meet the standards with no calibration changes that might affect fuel economy. For a system which has control capability well below 0.41 THC, a change to a NMHC basis may allow for spark advance recalibrations or compression ratio changes which might improve fuel economy (as long as octane problems do not arise). In addition to fuel economy improvements, reductions in system cost might be possible, as well as possibly some improvements in driveability. Although EPA can directionally identify these benefits of a NMHC standard, EPA cannot guarantee that gains in fuel economy and/or reductions in system cost and/or improvements in driveability will actually be made. How to apportion the potential benefits of a NMHC standard is a decision that will be made by each individual manufacturer.

Discussion of Conclusion 8

Compared to the efforts that would be expected to be seen if the statutory standards (0.41 HC, 3.4 CO, 0.4 NOx) were being pursued for 1978, the efforts of industry are low. Compared to the development efforts that would be required to meet standards of intermediate stringency in the near term, the efforts are also low. As reported last year, it appears that the industry is still pausing with emission control development pending amendment of the Clean Air Act.

During the last year, efforts on improved fuel metering and 3-way catalysts have received more emphasis. However, the efforts, especially in the very important area of testing durability vehicles with complete emission control systems, is lacking compared to what could be reasonably expected.

SECTION 3

DEVELOPMENT TRENDS

The development trends discussed below are considered to be the ones of the most technical interest that have become apparent during the past year. These trends are highlighted because they appear to be ones that show the possible directions for future development and effort toward meeting more stringent emission standards. Other efforts, such as the detailed system design, and evaluations of specific engine/vehicle applications and cost/effectiveness engineering studies are continually underway and may even consume more technical effort. However, the trends discussed in this section are considered to be more important in indicating the development directions.

3.1. Emission Control Systems Containing 3-Way Catalysts Are Receiving the Most Effort

The two most important generic systems now under development are the 3-way catalyst and the 3-way plus oxidation catalyst systems. These systems are variously referred to as 3-way, 3-way + ox. cat., or 3W + OC in this report.

Systems employing 3-way catalysts appear to be the ones that are being considered most seriously for future application and most manufacturers are working on such systems. This emphasis on systems employing 3-way catalysts has resulted in less emphasis on other systems that were under consideration, especially those targeted for low NOx standards.

The term "3-way catalyst" refers to a catalyst which has been specifically formulated for control of HC, CO, and NOx simultaneously in one catalyst bed. In physical appearance, a 3-way catalyst looks like an oxidation catalyst. The container and the size and the shape of the catalyst are virtually identical to the catalysts in use today. Three-way catalysts differ from conventional oxidation catalysts in the type of catalytically active material and washcoat preparation.

Most oxidation catalysts use platinum (Pt) or platinum/palladium (Pt/Pd) mixtures as active ingredients. Three-way catalysts typically use platinum/rhodium (Pt/Rh) mixtures as active noble metal ingredients. Some 3-way catalysts also use other active materials like nickel (Ni) for example.

To operate effectively, a 3-way catalyst must receive a precisely controlled exhaust gas mixture from the engine. This mixture must be very close to the chemically correct or stoichiometric mixture. The need for this precisely controlled exhaust gas mixture is why fuel metering systems involving feedback control are being developed for use in conjunction with 3-way catalysts. The feedback control allows adjustment of the engine's air-fuel ratio on a continuous basis, providing the correct exhaust gas composition to permit effective control of HC, CO, and NOx in one catalyst.

The type of development work that is potentially of the most importance has been the search for catalysts with low rhodium content. Since Rh plays a crucial role in determining the important properties of a 3-way catalyst such as efficiency, durability, NH_3 formation, etc., its supply availability is a matter of substantial debate and concern. This area is considered to be the most important development task remaining before the 3-way catalyst can be used on a widespread basis. Durability of the electronic controls and the oxygen sensor required for control of the 3-way system no longer appear to be areas of a major concern.

3.1.1. The Importance of "Mine-Mix" Rhodium Content for 3-Way Catalyst

Some of the better performing 3-way catalyst systems tested to date have used relatively high loadings of Rh compared to Pt. This ratio is usually expressed as the Pt/Rh ratio.

This ratio is considered by many to be a very important parameter because of the supply/production aspects of these precious metals. As the precious metals are produced, the naturally-occurring (the mine-mix) Pt/Rh ratio is approximately 19/1. Because the producers of precious metals will apparently be reluctant to increase Pt production just to get more Rh, it appears that the long-term ratio for Pt/Rh in automobile emission control systems will have to stabilize at a value close to 19/1 if additional Rh cannot be procured. There are other competitive uses for Rh so the prospects of using more Rh than the mine mix might involve higher costs for the Rh, which are already much higher in cost than Pt.

Increasing the Total Loading

If the catalyst performance is a function of the total Rh content (as opposed to Pt/Rh ratio), then one approach to attaining the desired performance is to increase the total noble metal loading. Three-way catalysts have shown reasonable performance at approximately 0.1 troy ounce total loading with a 5/1 Pt/Rh ratio. To get the same amount of Rh on a mine-mix catalyst (19/1), the total loading would have to be approximately tripled with cost and possible supply difficulties. Little work has been reported in this area.

Mine-Mix Redistribution on the Vehicle

Another approach is to consider a 3-way plus oxidation catalyst system with a total noble metal content of the two catalyst components that will reflect the mine-mix. Conceptually, this is achieved by depleting the Rh associated with the Pt that could be mixed for the oxidation catalyst and using this Rh to enrich the 3-way catalyst. This could allow the 3-way catalyst to be closer to 10/1 than 19/1, which may be enough to provide the necessary performance. Other types of redistribution could also be considered such as taking the palladium (Pd) associated with the Pt in the 3-way catalyst and adding it to the oxidation catalyst because Pd is a good catalyst for CO oxidation. Those manufacturers who are concentrating on the 3-way plus oxidation catalyst approach are considering this redistribution approach.

Conceptually this redistribution could occur within a single catalyst. If the noble metals could be distributed along the catalyst in a manner such that the first part of the catalyst had a low Pt/Rh ratio, that part of the catalyst might be an effective 3-way catalyst and the other part of the catalyst might be more effective as an oxidation catalyst. This approach could also be done by taking the separate 3-way and oxidation catalysts referred to above and placing them adjacent to each other, thus having a segmented catalyst. Some work has been reported in these areas.

Stockpiling Rh

A Pt/Rh ratio different from the mine-mix could also be used if the Rh associated with the Pt that will be used in the oxidation catalysts for the next few years were stockpiled and then used for a 3-way application. This approach could be used as a temporary measure only. Eventually the Pt/Rh ratio would have to approach the mine-mix ratio. For example, if Rh were stockpiled for 4 years, then one year would be satisfied at 5 times the mine-mix, 2 years at 3 times the mine-mix, 4 years at twice the mine-mix, etc.

The Mine-Mix Fleet

If a manufacturer does not need systems containing 3-way catalysts for all of his vehicles, then his entire fleet could be a mine-mix equivalent by increasing the Rh in the 3-way vehicles, and using Pt and/or Pt/Pd in the vehicles that use just oxidation catalysts. As the emission standards become more stringent, this approach might be less attractive on an industry-wide basis since the majority of the systems for use at more stringent emission standards for the near term are systems emphasizing 3-way catalysts.

Mine-Mix May be an Unnecessary Restriction

As the previous discussion has indicated, there is much concern with the issue of the mine mix Pt/Rh ratio for 3-way catalysts. There is, however, more Pt produced every year than that just for automobile catalyst use. This Pt, over and above the automobile catalyst requirement, has some Rh associated with it. The possibility exists that this Rh could be available for automobile catalysts, if the total non-automobile catalyst demand for Pt is for Pt alone, rather than for Rh and the other noble metals. If, for example, the customers for Pt do not need or want the Rh, then this Rh could be used for the automobile catalyst market.

It is difficult to determine precisely what the future supply of Rh will be. The worldwide noble metals supply and production appear to be somewhat of a cartel, dominated by the Union of South Africa and the Soviet Union*. Based on the inability of accurately determining what future Rh supplies are likely to be, the option of departing from the mine-mix Pt/Rh ratio for future 3-way catalysts cannot be ruled out, although most of the current emphasis is on the use of mine-mix catalysts.

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* Policy Implications of Producer Country Supply Restrictions: The World Platinum and Palladium Markets, Prepared for Experimental Technology Incentives Program, National Bureau of Standards, U.S. Department of Commerce, Contract #4-35960, Submitted by Charles River Associates Incorporated, 1050 Massachusetts Avenue, Cambridge, Mass., 02138, August 1976.

3.1.2. Improving the Catalysts

From a technical standpoint, the most satisfactory solution lies in improved catalysts. Work in the area of improved 3-way formulations can occur in two areas: (1) catalysts containing other materials that do not require the use of high Rh loadings and (2) the preparation of mine-mix catalysts.

Some work has been done to investigate replacing or augmenting Rh with other catalytic materials. While active work is underway, no materials have been reported to EPA that have superior catalytic performance for HC, CO, NOx, steam reforming, etc., with more favorable supply implications than Rh.

Ruthenium (Ru) has been studied extensively for both NOx catalyst and 3-way catalyst use but it has proved to be a difficult component to use effectively. Although it is a good NOx catalyst with excellent selectivity (low NH_3 production), the active formulations have not been stable (Ru is lost) and the stable formulations have not been particularly active. Periodically, claims for stabilization of Ru in an active state have been made but vehicle tests have generally been disappointing. The latest indication of Ru stabilization in an active state has been made by Ford, but the extensive vehicle tests needed to evaluate the on-vehicle performance have not been reported to EPA.

The bulk of the work on improved 3-way catalysts apparently has been in the area of improving the high mileage efficiency of the mine-mix Pt/Rh catalysts. Active material dispersion, improved washcoats, active material/washcoat interactions, and various combinations of the other (usually unspecified) active materials included in 3-way catalyst formulations are all under intensive study.

Mine-mix 3-way catalysts at their current state of development are probably adequate for control of NOx down to 1.0 NOx. To get NOx control significantly below 1.0 NOx, improvements in catalyst efficiency and/or improvements in engine-out NOx control are needed.

3.2. Improved Fuel Metering Systems Continue to Receive High Emphasis

The general area of improved fuel metering has been one that has always received great interest and emphasis. In the last year or so the trend has been to concentrate more on a given type of fuel metering. In the past, fuel metering systems were under consideration that spanned the range of nominal air-fuel ratio from rich systems for rich thermal reactors and dual catalyst systems through stoichiometric systems for 3-way catalyst systems to lean systems for lean thermal reactor, non-catalyst, or stratified charge systems. Now, the bulk of the fuel metering system development appears to be concentrated on stoichiometric systems with feedback control of air-fuel metering using an exhaust gas oxygen sensor. In addition, a trend is apparent, at least as far as the domestic manufacturers are concerned, which appears to emphasize feedback carburetion as contrasted to feedback fuel injection. The decision to concentrate on feedback carburetion may have been one in which cost considerations were paramount, since it has not yet been reported that feedback carburetion has any significant emissions, fuel economy, performance, or driveability advantages over feedback fuel injection.

There are a wide variety of fuel metering systems under consideration for application to future emission control systems. Some of their properties and EPA's estimate of the current emphasis being expended on such systems is shown in Table 3-1.

The choice of fuel metering system may be important as far as meeting future requirements for emissions. For example, the engine-out CO levels and the cold start emissions performance are considered two areas of importance for future systems.

Table 3-1

Types of Fuel Metering Systems

Descriptive Name of System	Fuel Introduced	Fuel Introduction Continuous (C) or Timed (T)	Typical Introduction (I) Control (C) Method	Remarks
Direct Cylinder	Directly into the cylinder	T	I - Mechanical C - Mechanical	Under study for Diesels and some stratified charge engines only.
Separate Cylinder Control	Into each intake port	T	I - Electromechanical C - Electronic	Very little reported with systems that control each injector independently
Multiple Simultaneous	Into each intake port	T	I - Electromechanical C - Electronic	Bosch D-and L-Jetronic. Some interest by foreign manufacturers
Continuous Mechanical	Into each intake port	C	I - Mechanical C - Mechanical	Bosch K-Jetronic is an example. High interest by European manufacturers
Central Point Injection	Upstream of Throttle plate	C	I - Electromechanical C - Electronic	1 or 2 injectors per engine. Some interest by domestic manufacturers.
Feedback Carburetion	Upstream of of throttle plate	C	I - Pneumatic/Mechanical C - Electronic/ Mechanical/ Pneumatic	Many different ways to implement air/fuel control under consideration High interest by domestic manufacturers.

1.3. Significant Use of Electronic Controls Appears to be a Relative Certainty in the Next Few Years

Electronic control of individual engine/system parameters such as spark timing and EGR is assured. It is clear that in the next few years electronic control of virtually all variable engine parameters will be integrated via microprocessors. These electronic systems may also monitor and/or control other, non-emission related systems.

The current trend appears to be one in which the control logic is obtained by means of stored computer memory in the form of stored digital data, or "look-up tables". For a given set of sensed parameters, the lookup tables will provide information as to what the controlled parameters should be. Little work has been reported on dynamic logic systems that would actually compute the outputs as a function of the inputs. Therefore, the current emphasis is on obtaining engine data for the values required in the look-up tables.

The full impacts of the widespread use of electronic control systems on the manufacturing, supply, service, and regulatory aspects of the automobile industry have yet to be determined.

Two areas, the impact on the service industry and the emissions impact of the widespread use of electronic controls should be highlighted. Electronic control systems could have positive implications for the service industry. If the control units could be used to generate information when hooked up to a diagnostic instrument, identification of problems could be done quickly and accurately, with potential benefits to the public in terms of maintenance quality and cost. This potential benefit would of course require one type of diagnostic instrument that could be used for all vehicles. Unfortunately there appears to be no trend in the direction of supplying the compatibility needed in order to have one common diagnostic instrument be effective. In practice, a specialized diagnostic instrument might be required for GM vehicles, a completely different one for Ford vehicles, etc. While the impact of this diversity on new-car dealers might be slight, the impact on the rest of the service industry would be most significant. It is not realistic to expect all independent service organizations to be able to afford to buy and store several different types of specialized electronic diagnostic equipment. If the independent service industry cannot service most kinds of vehicles, as it does today, their business may be negatively affected. Not having the capability in the service industry to deal with a wide range of vehicles could also have a negative impact on Inspection and Maintenance (I/M) programs. A requirement that service compatibility be considered in the initial design and development of electronic control systems has obvious trade secret and anti-trust problems. Thus, how to service electronic controls in the field raises unanswered questions.

The emissions impact of electronic controls is also of concern to EPA. Most systems will have some sort of failure mode logic in them, i.e., when an inappropriate signal is received from a sensor, or when part of the system fails, there will be some sort of operational mode that will be used until the vehicle can be fixed. Exactly what these modes will be, how the vehicle driver will know that something is wrong and needs to be fixed, and the emissions produced during these modes are currently unknown.

Another emissions-related area of concern to EPA is how the electronic control systems will be programmed to operate under conditions that are only slightly different from the very specific conditions of the official EPA emissions test. The degree to which emission control may be sacrificed when the vehicle is operating under slightly different conditions could be a concern, by opening entirely new ways of introducing hard-to-spot

Defeat Devices. Electronic controls will provide a great amount of flexibility to the vehicle designer and EPA will have to take steps to ensure that this flexibility does not result in excessive emissions during environmental and driving conditions different from the FTP test specifications.

3.4. Non-Catalytic Engine and Emission Control Technology is Also Showing Some Interesting Developments

Two examples of progress made in the area of engine technology and non-catalytic emission control systems are those reported by Nissan and Ethyl.

Nissan has made modifications to a conventional engine that have shown low mileage NOx results below 0.4 NOx without catalytic control of NOx. The Nissan approach is basically a twin spark plug cylinder head. The use of two spark plugs apparently increases the EGR tolerance of the engine thus allowing use of increased EGR rates for better NOx control. HC and CO are controlled via an oxidation catalyst. It remains to be seen, however, if the HC and CO emissions can be controlled to the required levels at high mileage. Low mileage emission results below the statutory levels were reported by Nissan, with fuel economy equivalent to their 1977 vehicles.

What perhaps is most important about the Nissan results is that they demonstrate that further advances in the control of the basic engine's emissions are still possible. Successful implementation of such an approach might indicate that meeting NOx levels below 1.0 NOx without catalytic control of NOx may be possible for relatively lightweight vehicles such as the one tested by Nissan. This may have positive implications in allowing higher Pt/Rh ratios (i.e. closer to mine-mix) for vehicles that require a system containing a 3-way catalyst to get below 1.0 NOx.

It remains to be seen how transferable the twin plug/high EGR rate approach is to other engine/vehicle combinations. It should be pointed out, however, that cylinder head design/development/production is an area in which the industry has a great deal of knowledge and experience.

The Ethyl results also show progress in the non-catalytic emission control system area. The Ethyl Corporation, one of the major suppliers of tetraethyl lead additive for gasoline, has long been interested in emission control systems that are compatible with leaded fuel operation. Ethyl's current systems are a refinement of their improved mixture preparation and distribution/thermal reactor system. Ethyl's results show extremely low HC (values at or below 0.10 HC) and low CO (below 3.4 CO) at low mileage and are considered to be important advances because they show that non-catalytic emission control systems can be designed to have low HC and CO emissions. The greater than 90 per cent reductions in HC and CO emissions from the baseline were achieved with fuel economy results approximately 10 per cent lower than the baseline vehicles. The fuel economy results obtained by Ethyl on one advanced prototype vehicle was approximately 9 per cent better than the nearest comparable 1977 certification vehicle. The emission results are also important because they show promise for systems that combine technology like that under development by Ethyl with catalyst technology. HC control with such a system could be good enough to eliminate the need for any compromises in spark timing with a concomitant positive impact on fuel economy.

Taken together, the Nissan and the Ethyl results could be conceptually combined to infer that control to levels below 0.41 HC, 3.4 CO, 0.4 NOx might be possible with a non-catalytic, conventional engine based system. A more important conclusion is that emission control advancements are being made in areas other than just catalysts. Basic engine controls, such as Nissan's, and non-catalytic emission controls such as Ethyl's, are continually being reported. Such developments tend to lower the emission levels that can be achieved, with or without catalysts, and are examples of developments, not previously reported, that can change the conclusions about the capabilities to control emissions with various types of emission control technology.

3.5. Catalyst Developments Other Than the 3-Way Catalyst Are Also of Interest

Two areas of interest in the catalyst field, other than the 3-way catalyst efforts, are considered important. They are perovskite catalysts and metallic substrate monoliths.

Perovskite-based catalysts have received some interest in the past year. The HC conversion efficiency is apparently still not competitive with conventional catalysts and these catalysts still must be operated at a higher temperature than most conventional catalysts. However the potential of this approach for NOx control may not have been fully evaluated because little effort is being expended in the NOx catalyst area now.

On balance, the development of perovskite catalysts may have been somewhat of a blind alley although there is not universal agreement on this point. Perovskites serve as an example of why the time and effort it takes to pursue initially promising developments leads to the requirement for much research and preliminary development work in the emission control field.

Most of the substrates in use today for monolithic catalysts are non-metallic, ceramic-based materials employing a typical cell density of 300 cells (or passageways) per square inch. Recently there has been some interest shown in monoliths with metallic substrates. If the substrates can be effectively coated then some improvements in catalyst performance might be expected since metallic substrates can be made with significantly higher cell densities than with current ceramic substrates. A potential problem however might be plugging of cells with deposits such as combustion products of MMT or ash components of lubricating oils.

The application of metallic substrates could produce two benefits. For a given catalyst volume, emission control performance could be improved.

On the other hand, at a given emission control level, catalyst size (i.e. weight and cost could be reduced). Metallic substrates may have other properties that need to be investigated. They may reduce the need for special mounting techniques now used between the substrate and the catalyst can. On the other hand, they may conduct heat away from the front face too quickly - delaying front-end catalyst light-off. Finally, the potential emission products of such substrates need to be investigated, especially with fuels containing representative (i.e. higher than past) levels of fuel sulfur.

3.6. There Are Indications That the Space Required for Emission Control Systems May Become a Future Problem

The potential problem is this: New generations of automobile designs are being designed and developed in an attempt to comply with future fuel economy requirements and EPA is beginning to receive indications that the space availability required for future emission control systems may not be adequate in these future vehicles. It is too early to tell if this is going to be a significant issue, but if it becomes one, the emission control and/or fuel economy consequences could be serious.

3.7. Turbocharging as a Means to Increase Vehicle Performance Is an Active Area

Some of the approaches to improved fuel economy can have negative vehicle performance attributes. Two examples are: (1) reducing the vehicle power to weight ratio, generally by installation of an engine with smaller displacement and (2) decreasing the numerical value of the axle ratio.

In order to attempt to maintain or improve vehicle performance while fuel economy improvements are made, some manufacturers are exploring the possibility of using turbochargers to increase engine output. Basically, a turbocharger is a supercharger which uses a turbine in the exhaust flow to drive a compressor which in turn compresses the intake charge. The resulting increase in manifold pressure allows the induction and combustion of more air-fuel charge in a given amount of time, thus generating more power.

Turbocharged gasoline engines are under investigation by GM and Saab and one is currently available on a Porsche model. Daimler-Benz and VW are experimenting with turbocharged Diesel engines.

In theory, a vehicle equipped with a turbocharger could have the same fuel economy as a vehicle with a naturally aspirated engine, of the same displacement, while delivering performance equivalent to a larger displacement engine. In practice, both of these goals may not both be completely achieved, with the emphasis being more directed toward fuel economy for some manufacturers and performance for other manufacturers.

The emission impact of turbocharging has not been quantitatively determined at this point in time. Data reported to EPA to date indicate that emission performance equivalent to naturally aspirated engines can be achieved.

Little information exists with turbocharged vehicles targeted toward low emission levels, so conjecture about the thermal inertia of the turbocharger delaying catalyst light-off cannot be confirmed. Based on the information available, it appears that turbocharging has neither a positive nor a negative impact on vehicle emission control.

3.8. Diesel Engine Development Continues to Receive Emphasis - But the Development Work on the Diesel's Problem Areas Does Not Seem to be Receiving the Intensive Effort Which May be Necessary to Meet Stringent Emission Standards

More and more manufacturers have reported work on investigating the possible application of Diesel engines to automobiles. Among those who have worked or are working on Diesels are: GM, Ford, Chrysler, Isuzu, VW, Volvo, Nissan, BMW, Daimler-Benz, Peugeot, Fiat, Toyota, Alfa Romeo, and British Leyland. It can be seen that the interest is widespread. Certain engineering society members have even recommended research and development into specific Diesel subjects.*

While widespread, this interest generally has been in the areas of the Dieselization of gasoline engines and investigations of some of the areas in which Diesel powered vehicles have been expected to be somewhat different from gasoline engine powered vehicles, like noise and performance.

In addition to the development and evaluation work reported to EPA, several manufacturers took the opportunity to comment on their views of the low emission capability of the Diesel. The comments generally reflected opinions that the Diesel would be ruled out at some specific NOx level. These claims have been made and these positions have been discussed for at least 5 years. However, the data needed to back up these claims and assertions were generally not supplied. EPA has pointed out for several years now that the emission challenge for the Diesel lies in particulate and NOx control. This control will require an extensive research and development effort. Based on the development efforts reported to EPA, the efforts expended in this area appear to be less than is expected to be necessary. Controlling Diesel particulate and NOx emissions may require a development effort equal to, or greater than, that expended for the development of the catalytic converter for gasoline engines.

As an example of the magnitude of the problem, a catalyst-equipped gasoline engined-vehicle emits about 0.02 to 0.05 grams per mile total particulate. Current Diesels emit about 0.40 grams per mile total particulate, somewhere from 8 to 40 times greater than a gasoline engine powered vehicle.

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* Automotive News, 28 February 1976, page 88.

Control of NOx to low levels may tend to increase particulate emissions. It appears that with the use of EGR, Diesels can achieve low NOx values, below 1.0 NOx and possibly below 0.4 NOx. More exotic systems such as those involving Variable Compression Ratio (VCR) pistons* have also been projected to meet low NOx (below 0.4 NOx) levels. Although interesting and encouraging, the VCR work presents only computer projections, not vehicle data, and the smoke, odor, and particulate characteristics are not well known. If EGR (used for low NOx levels) increases particulate emissions, the total particulate from Diesels might be 50 or more times greater than the total particulate from gasoline-fueled vehicles using unleaded gasoline.

The possible increase in total particulate may indicate that extensive effort may be needed to control Diesel particulate, since there are indications that a large number of Diesel vehicles at 0.40 grams per mile total particulate may exacerbate the Total Suspended Particulate (TSP) burden in many Air Quality Control Regions.**

It is not clear, however, that the total mass of particulate emissions from automobiles is the most appropriate way to characterize the particulate emissions. Particulate size, size distribution, and chemical nature all may be important in terms of air quality and/or health implications. EPA has Diesel particulate under study, but it is a difficult and complex subject and the information that could support the setting of a particulate emission standard appears to be a long time away.

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* A Low NOx Lightweight Car Diesel, by S. H. Hill and J. L. Dodd SAE paper 770430, presented at the 1977 SAE Congress, 3 March 1977.

** Air Quality, Noise and Health, Report of a Panel of the Interagency Task Force on Motor Vehicle Goals Beyond 1980, March 1976.

The lack of specific information as to what levels of Diesel particulate will be considered acceptable may be one of the reasons why so little has been reported in the control technology area. Lacking standarized test procedures and a clear idea of acceptable tailpipe levels, the developers may find it difficult to choose effective control technology. Traps and combustion modifications appear to be two of the general approaches that could be considered, although not much in either area has been reported to EPA.

3.9. The Efficiency at Which Development Information on Emissions Related Subjects is Reported to EPA May Be Decreasing

In order to prepare this Status Report, EPA solicits from U.S. and foreign manufacturers information on their development programs for emission-related technology. The responses requested from the manufacturers are expected to be full and complete descriptions of their emission-related development programs. However, EPA technical staff have reason to believe that not all of the development effort on emissions-related work may be completely reported to EPA in a timely fashion.

As an indication of the nature of the information which has apparently not been completely reported to EPA, the following examples are given.

New Engine Development Programs

The development and introduction of a basically new engine is a substantial undertaking. A new engine is defined here as one that requires a new or different engine block or is a different method of combustion, for example Diesel versus homogeneous spark ignition. It is generally accepted that such a program takes a significant period of time.

New engines are expected to be technologically improved over older engines, and it is not unreasonable for EPA to expect that improved emission performance would be considered in the design and development of new engines. Therefore, the reporting of the development of new engines is considered important by EPA. Recent examples of new engine developments not previously reported to EPA are projects of Volvo, GM, and VW.

Volvo started a development program on a Diesel engine with Ricardo & Company in 1974. To date, 6 vehicles have been equipped with this Ricardo/Volvo engine. The first time that Volvo reported the information concerning this engine development project was in their 1976 Status Report to EPA.

GM has reported development work on V-6 configuration engines, as it pertains to the Buick 231 cubic inch engine and its derivatives. The existence of GM's plans to produce an all-new V-6 engine completely different from the Buick V-6 has been recently reported in a trade publication.* A Chevrolet V-6 (200 CID) engine was found in the 1978 GM Application for Certification, but GM did not report the development of this engine in their status report.

The basic information that VW presented on their Diesel engine concerned their 4-cylinder engine. However, under their contract with the U.S. Department of Transportation (DOT/TSC 1193), VW is to provide information (including emissions data) on 4, 5, and 6 cylinder Diesel engines. The work on the 5 and 6 cylinder Diesel engines was not reported to EPA.

VW's progress in the development of a vehicular, ceramic, gas turbine engine has been reported in the press.** Tests have apparently been run, yielding claims for better fuel economy than vehicles equipped with gasoline engines. The engine is also reported to have been designed for low emissions. VW did not report any information about this engine to EPA.

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* Ward's Engine Update, 10 December 1976, Volume 2, Number 25, page 3.

** Automotive News, 28 February 1976.

Electronic Controls

In this rapidly expanding area some work is now being reported to EPA. Apparently, some of the work had been ongoing for some time before the results were reported to EPA.

Because electronic controls offer flexibility to the emission control engineer that mechanical systems may lack, electronic controls are important. They may alter relationships between emission control and fuel economy that may have existed in the past. As long as EPA is unaware of the actual status of development of such new technology, EPA will tend to undervalue the emission control and fuel economy benefits and overstate the time it would take to implement such new technology.

GM first reported work on what was eventually to become the MISAR electronic spark control system in 1975 in their Application for Suspension.* However, according to the Application for Suspension and a publication** the development started in 1970 and took six years before it was introduced for model year 1977 in limited production.

GM did not report test results on a spark knock sensor in their status report. The GM status report did report that they are working on a combination of a knock-actuated spark control system and increased compression ratio. EPA has recently learned, however, from the 1978 GM Application for Certification that GM plans to introduce a knock-actuated spark control system in model year 1978 on a vehicle using a turbocharger, not on a vehicle using increased compression ratio.

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* "General Motors Application for Suspension of the 1977 Federal Emission Standards," 10 January 1975, Volume III, Appendix B, pages 3-4.

**Simanaitis, Dennis J., Automotive Engineering, January 1977, Volume 85, Number 1, page 29.

Turbocharging

GM and Saab indicated in their 1976 status reports that they plan to introduce turbocharged vehicles for model year 1978. Neither Saab nor GM reported development of turbocharged engines in their 1975 status reports. Either it takes less than one year to design, develop, test and commit to production for a turbocharger, or work was underway earlier and not reported to EPA.

GM* and Ford** have also been reported as having development work underway on turbocharged engines that were not reported to EPA. GM did report "many programs in GM to develop turbocharged engines", though only a V-6 engine was discussed and a Vega engine was mentioned in passing.

Mechanical Octane Improvements

The spark timing calibrations and compression ratio of an engine influence its emission and fuel economy characteristics. Any changes in the octane requirements of an engine may allow alterations in spark timing calibrations and/or compression ratio. It has been reported*** that Saab has developed a method to allow for increased compression ratio. This work was not reported by Saab in their status report to EPA.

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* Ward's Engine Updated, 18 February 1977, Volume 3, Number 4, pages 1 and 8.

** Automotive News, 7 March 1977, page 43

*** Automotive News, 28 February 1977, page 61.

Transmissions

The automobile industry is studying the impact of improved transmissions. Much of the interest has been on multispeed torque converters with lockup clutches for improved fuel economy. For example a recent technical paper* projected substantial gains in fuel economy (in excess of 15%) with the use of such a transmission.

The emissions produced by the engine may be altered with use of a lockup transmission because the torque/speed relationships during the test are changed. The transmission is an important part of an automobile's emission control system. Very little in the way of the emissions from advanced transmissions/advanced emission control systems has been reported to EPA. It does not seem reasonable that experimental and/or analytical work has not been done. Rather it appears more likely that the work has not been reported.

Catalysts

GM reported running a fleet of possibly improved catalysts in their status report. When asked by EPA for the data on the then incomplete program, GM indicated that they would not provide the data until they were done with the program and had time to analyze the information themselves.

The above examples show that EPA may not be kept abreast of technological developments as much as is necessary. For the preparation of a report of this type, there is not enough time to go back to all the manufacturers and get continual updates of their programs, as areas not reported fully become known. EPA has to rely to a large extent on the manufacturers to supply full and complete reports so that EPA can make its own timely judgments as to what the data mean. Not getting important data on a timely basis can only hamper EPA's estimates of future emission control capability.

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* Chana, Howard E., et al., "An Analytical Study of Transmission Modifications as Related to Vehicle Performance and Economy, SAE Paper Number 770418.

EPA technical staff realize that the preparation of responses to the EPA requests for information on progress is a difficult undertaking, and that some degree of judgment is required in deciding what to include in the response. However, the foregoing items of data that were not completely reported appear on their face to be so significant as to raise questions as to why they were not reported; it seems unlikely that they were screened out as being too unimportant to mention. Thus some thought on how reports of this type are to be prepared in the future is in order, to assure that these annual reports can continue to serve the important purposes for which they are prepared.

SECTION 4

FUEL ECONOMY AND COST

4.1. Fuel Economy

The Federally-mandated fuel economy standards for automobiles are: 1978, 18.0 MPG_c; 1979, 19.0 MPG_c; 1980, 20.0 MPG_c; 1981, 1984 to be determined by the Secretary of Transportation; 1985, 27.5 MPG_c.

Projecting of the fuel economy of automobiles in future model years is a difficult and complex task. EPA has recently participated in two such studies. The first study was entitled "Analysis of Some Effects of Several Specified Alternative Automobile Emission Control Schedules" and was published on April 8, 1976. Other participants in the study were the U.S. Department of Transportation and the Federal Energy Administration. The second study was entitled "Analysis of Effects of Several Specified Alternative Automobile Emission Control Schedules Upon Fuel Economy and Costs" and was published in February of 1977. These studies will hereafter be referred to as Study 1 and Study 2.

Studies 1 and 2 have indicated that:

1) The impact of emission standards on fuel economy for future model years for various postulated emission standards cannot be specified as a single value due to uncertainties in projecting which fuel economy and emission control technologies will be used in the future by the automobile manufacturers. The impacts are best expressed as a range of possible outcomes.

2) If advanced emission control technology, that is now in the prototype stage can be integrated into effective emission control systems, there need be no negative impact on fuel economy due to stringent emission standards in the future.

3) The fuel economy standards for future model years can be met at any future level of emission standards considered. However, meeting 0.41 HC together with either 1.0 NOx or 0.4 NOx will require the use of more sophisticated emission control hardware than would be required at less stringent NOx levels.

The data from Studies 1 and 2 provide input for the EPA estimates of fuel economy later in this section.

4.1.1. An Historical Look at the Fuel Economy of Various Manufacturers

Before various fuel economy estimates are discussed, it is worthwhile to look at historical trends in fuel economy.

Sales weighted fuel economy data for various vehicle manufacturers are presented in Table FE-1. Of particular interest in this table is the fact that in terms of sales projections for 1977 only Ford, Chrysler, Rolls Royce, and Checker were under the 18.0 composite fuel economy level required for model year 1978; The actual sales weighted fuel economy levels may of course change when actual 1977 production data are available. The 1977 values in Table FE-1 are revisions to the values presented in SAE paper number 760795* which were based on earlier data.

Figure FE-1 depicts the changes in the sales weighted fuel economy of the complete industry which have occurred as a function of time over the past and present model years.

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* J. D. Murrell, et al., "Light Duty Automotive Fuel Economy - Trends Through 1977", SAE Paper 760795.

Table III-1

50 State Fuel Economy for Various Manufacturers

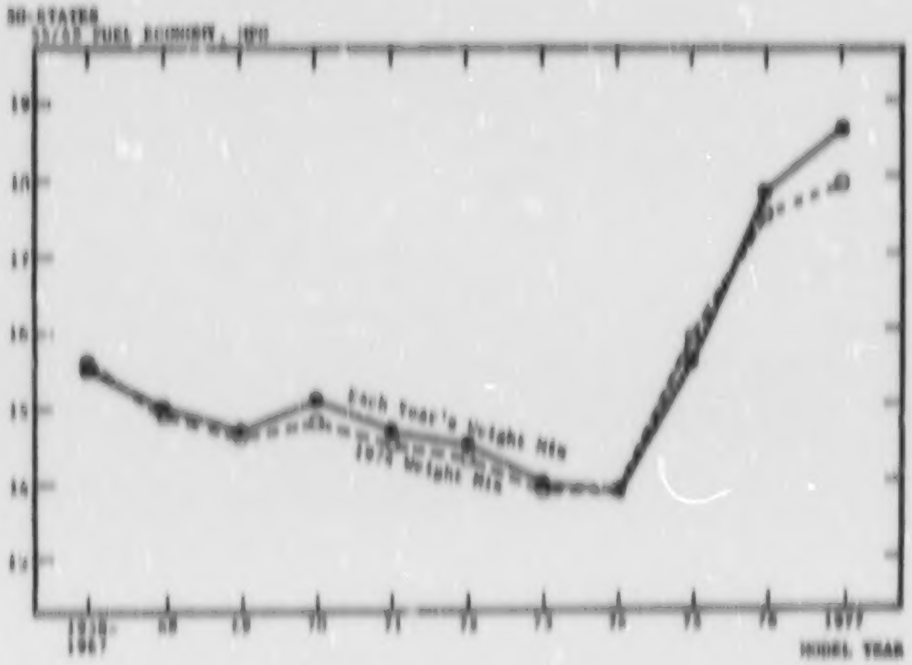
Manufacturer		1974	1975	1976	1977
GM	MPG_u	10.54	13.46	14.50	15.65
	MPG_h	14.55	18.57	20.28	21.87
	MPG_c	12.03	15.42	16.64	18.28
Ford		12.67	13.86	15.19	14.91
		18.62	17.11	20.96	20.72
		14.80	15.66	17.36	17.07
Chrysler		11.80	13.45	14.27	14.29
		17.08	19.28	20.03	20.58
		13.75	15.54	16.39	16.57
AMC		14.40	16.77	16.15	16.87
		19.52	21.57	21.85	22.27
		16.37	18.86	18.29	18.83
VW		22.61	23.06	22.05	25.88
		35.05	35.62	34.32	38.48
		26.81	27.38	26.80	30.35
Toyota		19.19	18.92	21.19	24.74
		28.39	28.17	31.97	35.45
		22.52	22.17	24.95	28.46
Nissan		20.69	21.46	21.46	23.81
		30.80	31.89	31.67	32.72
		24.05	24.96	25.08	27.13
Volvo		16.55	16.3	16.45	17.01
		24.68	24.42	24.75	25.28
		19.42	19.21	19.37	19.94
Audi		18.14	18.33	22.80	22.74
		25.67	31.50	30.85	32.77
		20.78	24.21	25.17	25.81
Fiat		19.09	19.88	19.96	19.88
		27.01	27.12	28.70	30.15
		21.85	21.86	21.05	23.48
Triumph (BLMC)		19.3	20.35	20.82	22.65
		27.7	28.22	28.46	31.82
		22.1	23.57	21.98	25.99
Saab		18.41	21.15	20.80	23.64
		21.81	25.25	27.30	28.95
		19.86	22.81	22.82	23.78
Fuji		27.5	23.30	26.46	32.17
		33.8	32.11	35.02	37.88
		25.7	26.51	28.78	30.16
Daimler-Benz		17.30	19.88	16.37	17.19
		18.76	22.25	22.52	22.48
		15.38	17.35	18.62	19.28
Honda		26.85	27.16	28.47	31.51
		36.90	38.36	38.60	42.59
		31.11	31.27	32.62	35.35
Toyo Kogyo		11.68	14.36	18.85	20.59
		17.07	20.87	27.19	32.88
		13.62	16.73	21.85	20.85

Manufacturer		1974	1975	1976	1977
Porsche		17.5	16.36	17.14	16.71
		27.3	25.88	26.98	27.74
		20.4	19.76	20.40	20.70
R.R.		8.1	9.03	10.03	9.87
		10.9	12.05	13.22	12.61
		9.2	10.17	11.25	11.11
Alfa Romeo		20.6	19.46	19.48	22.59
		26.8	25.36	26.98	30.42
		23.0	21.66	22.24	24.99
Jaguar (BLMC)		9.6	10.95	10.93	11.37
		13.9	16.10	15.57	15.92
		11.0	12.81	12.51	12.85
Renault		25.6	23.52		23.35
		31.9	32.33		37.75
		28.1	26.85		28.11
Peugeot		18.38	19.90	19.73	20.34
		23.85	27.51	26.23	28.12
		20.98	21.76	22.11	26.15
BMW		16.49	15.41	16.52	17.71
		24.79	22.93	22.96	25.11
		18.54	18.11	18.95	20.40
Austin-Morris (BLMC)		22.6	20.57	18.42	17.75
		31.2	31.66	31.87	28.67
		24.8	23.40	21.74	21.67
Checker			14.98	15.70	15.56
			18.49	18.24	18.96
			16.33	17.30	17.38
MG (BLMC)		17.3	18.48	18.26	19.4
		24.8	26.38	27.40	27.7
		20.1	21.39	21.41	22.7
All companies	MPG_c		15.96	17.78	18.66

Production sales values used for 1974 whenever possible.
1975, 1976, and 1977 estimate based on estimated sales.

Figure FE-1

Automotive Fuel Economy As a Function of Time*



* SAE Paper 760795

It is important that in 1977 the sales weighted fuel economy of the California fleet (calculated using the appropriate California sales) was virtually equivalent to the sales weighted fuel economy of the 49-state fleet (calculated using the appropriate Federal sales fractions) despite the large difference in emission standards between the two fleets. These data are shown in Table FE-2.

Table FE-2

Fuel Economy of the 49-State, California, and 50-State Fleets

	MPG		
	49-State Fleet	California Fleet	50-State Fleet
Domestic Vehicles	17.82	15.94	17.68
Imported Vehicles	27.70	26.05	27.29
All Vehicles	18.66	18.49	18.64

The values in Table FE-2 for all vehicles were previously reported to be 18.6 for the 49-state fleet and 18.0 for the California fleet by J. D. Murrell, et al.* These values were based on earlier data than used in this report. Since some of the foreign manufacturers had not certified at the time of the Murrell paper, the fuel economies of both fleets increased as more vehicles were certified.

An explanation for the nearly equivalent fuel economy between the 49-state fleet meeting 1.5 HC, 15 CO, 2.0 NOx and California fleet meeting 0.41 HC, 9 CO, 1.5 NOx is that the sales weighted inertia weights between the two fleets are different. The sales weighted inertia weight of the 49-state fleet is about 3930 pounds and the California fleet is about 3520 pounds. The main reason for the difference in inertia weight is that a higher proportion of the vehicles sold in California are imports as shown in Table FE-3. The inertia weight of the 49-state fleet is expected to more closely resemble the California fleet in future model years as weight reduction programs are implemented by the domestic vehicle manufacturers.

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* J. D. Murrell, et al., "Light Duty Automotive Fuel Economy - Trends Through 1977", SAE Paper 760795.

Table FE-3

Fraction of 50-State Fleet Sales

	49-State Fleet	California Fleet	50-State Fleet
Domestic Vehicles	0.7938	0.0593	0.8531
Imported Vehicles	0.1145	0.0324	0.1469
All Vehicles	0.9083	0.0917	1.0000

Fuel economy estimates which were made for the 1977 model year by various sources are shown in Table FE-4. The Federal emission standards changed from 1.5 HC, 15 CO, 3.1 NOx in 1976 to 1.5 HC, 15 CO, 2.0 NOx in 1977.

Table FE-4

Previous Estimates of Changes in Fuel Economy of 1977 Federal Vehicles

Source of Estimate	Estimate	Actual Change
Chrysler	7% loss for Chrysler, compared to 1976	0% for Chrysler
Ford	no estimate given	0% for Ford
GM	5% loss for GM, compared to what could be accomplished at 3.1 NOx	+9% for GM
Study 1	5% to 8% increase compared to 1976	+5% for Fleet
Study 2	no estimate given	+5% for Fleet

4.1.2. Comparison of Fuel Economy Estimates at Various Emission Levels Between Three Domestic Vehicle Manufacturers and EPA

The most important consideration in projecting the fuel economy of future vehicles are 1) the applicable emission standard, 2) the applicable model year, 3) the technology which is assumed to be available in a given model year to the manufacturer, 4) the changes in vehicle weight which are assumed to be applicable for a given model year. When considering per cent changes in fuel economy, the base year or reference point in time is also of importance.

The recent status reports to EPA from Chrysler, Ford, and General Motors contained the estimates of comparative vehicle fuel economy at various emission levels compiled by these respective manufacturers. The EPA estimates will be compared to the industry estimates of the impact of emission standards on fuel economy in this section.

The submissions of the three manufacturers which are most important to this discussion are presented as Table FE-5 to FE-7. These tables were extracted directly from the manufacturers' submissions to EPA.

Table III-5

GM Fuel Economy Estimates

(From GM Submission)

	Standards			Potential System Hardware	Fuel Economy Losses		Remarks
	HC	CO	NOx		Percent	MPG (18.4 MPG Base)	
1977 Federal	1.5	15	2.0	Ox. Converter, EGR	Baseline	18.4[1]	Includes a 5% fuel economy loss from 1975 standards (1.5/15/2.0).
1978-81 [illegible]	.9	3.0	2.0	Ox. Converter, AIR, EGR	0	18.4	Lead time requirements would prevent AIR and EFE usage in 1978.
1982 [illegible]	.41	3.4	2.0	Ox. Converter, AIR, EGR	10-20	16.7-14.8	Further improved catalyst system performance and durability for 1978 and later years may reduce penalty to lower end of range shown. "Current" systems show penalties up to 20%.
1977 California	.41	9.0	1.5	Ox. Converter, AIR, EGR	0[2]	18.4	Limited product availability.
Conference Report	.41	3.4	1.0	Large Engine/Axle for Ox. Converter, AIR, EGR	15-20	15.9-15.6	Larger engines and higher axle ratios reduce NOx emissions by reducing engine load.
				3-way converter CL, EGR	5-20	14.7-16.6*	
				Dual Converter CL, AIR, EGR	10-20	14.7-16.6	The fuel economy losses may be at the lower end of the range only if satisfactory catalyst durability can be developed and an adequate supply of catalyst material is available. To date, no system has been developed that meets EPA emission test requirements for 50,000 miles with reasonable maintenance requirements.
1978 Statutory	.41	3.4	0.4	Same catalyst system alternatives as .41/3.4/1.0 NOx.	10-20	14.7-16.6	Meaningful assessment of fuel economy penalty cannot be made since control systems have not been demonstrated to meet statutory standards through the complete certification process including the 50,000 mile durability requirements.

(1) EPA calculation of 1977 GM fleet average based on Part I Certification sales forecasts.

(2) Loss would be more than 0% if California's emission allowances, [illegible] requirements, and carry across of Federal durability data were not permitted.

Note: Diesel engines are not included but are discussed in Section III. A.

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* Fuel economy value changed to 15.4 MPG by GM. Change communicated to EPA by letter dated 21 December 1973.

Table FE-6

Ford Fuel Economy Estimates
(From Ford Submission)

FORD MOTOR COMPANY

PROJECTED PERCENTAGE EFFECT OF VARIOUS EMISSIONS STANDARDS ON CORPORATE AVERAGE U.S. PASSENGER CAR FUEL ECONOMY AND PRICE

MODEL YEAR	EMISSION CONTROL SYSTEM DESCRIPTION	AVERAGE U-H FUEL ECONOMY PERCENT B/(W) THAN BASE 1.5/15/2.0	0.9/9/2.0	0.41/3.4/2.0	0.41/9/1.0	0.41/3.4/1.0	RETAIL PRICE EQUIVALENT (B)/W BASE a/
77/78 Fed 77/78 Cal	Opt. Conventional, HC/CO Catalyst, lean A/F, EGR As above	BASE	(5%)	(11%)	(10-17%) (11%)b/	NONE	BASE
79/80 Fed	Opt. Conventional, HC/CO Catalyst, Air, ESC/EEGR	16	1	(8)	(11)	NONE	$(140-220)
79 Cal/ 81 Fed No Sulfate Standard	TWC, HC/CO, Air, EGR, Carb Feedback			(3)	(4)	(11)	$(150-220)
	TWC, HC/CO, Air, Carb. Feedback, ESC/EEGR			0	(1)	(3)	$(220-290)
	TWC, HC/CO, Air, EEC (EFM, F'back, EEGR, ESC)			9	1	(1)	$(280-360)
1981 With Sulfate Standard (15 mg/mi)	As above, and managed air			(13)	(16)	NONE	NA
	" " " " "			(8)	(9)	(11)	NA
	" " " " "			(5)	(6)	(9)	NA
	" " " " "			(8)	(6)	(6)	NA

a/ System and emission level assumed for costing is indicated by ☐; Costing based on hardware levels currently under development.

b/ California penalty less than if the car was certified for 49 States at same emissions because of unique California certification regulations with respect to 50,000 mile durability car requirements and standards in terms of non-methane hydrocarbons.

NONE Does not meet emissions requirements.

NA Not Available

HC/CO HC/CO is a Hydrocarbon, Carbon Monoxide oxidation catalyst.

TWC Three-way catalyst

ESC Electronic spark control

EEGR Electronic exhaust gas recirculation

EEC Electronic engine control (integrated controls for fuel, with feedback, exhaust gas recirculation, and spark).

Data on this page subject to change on a monthly basis as development progresses.

B/(W) = Better/(Worse)

Table FE-7

Chrysler Fuel Economy Estimates
(From Chrysler Submission)

			EPA Composite Fuel Economy	
HC	CO	NOx	Percent Individual Step	Percent Cumulative
1.5	15	3.1	Base	Base
1.5	15	2.0	-5%	-5%
0.9	9	2.0	-3%	-8%
0.4	3.4	2.0	-3%	-11%
0.4	3.4	1.5	-3%	-14%
0.4	3.4	1.0	-3%	-17%
0.4	3.4	0.4	*	*

* No Chrysler data available upon which an estimate can be made. No catalyst system appears caprble of achieving these low levels with adequate durability.

Table FE-8

Fuel Economy at 0.9 HC, 9 CO, 2.0 NOx

Model Year	Source	Estimated % Change in Fuel Economy	Technology Assumed Available
1978	Chrysler	(-3)	Proven technology
	Ford	-2	EGR/OC
	GM	NE	-
	Study 1	+3 to +9	PL/EEGR/ESA/AIR/OC/RC
	Study 2	NE	-
1979	Chrysler	(-3)	Proven technology
	Ford	+1	ESC/EEGR/AIR/OC
	GM	NE	-
	Study 1	+6 to +13	same
	Study 2	NE	-
1980	Chrysler	(-3)	Proven technology
	Ford	+1	ESC/EEGR/AIR/OC
	GM	0	AIR/EGR/OC
	Study 1	+8 to +15	same
	Study 2	+12 to +15	same as Study 1
1981	Chrysler	(-3)	Proven technology
	Ford	NE	
	GM	0	AIR/EGR/OC
	Study 1	+10 to +17	same
	Study 2	+15 to +17	same

NE = no estimate

To facilitate comparisons of the data, Table FE-8 to FE-11 have been generated to more clearly illustrate the estimates from the various sources with respect to emission standards. The Chrysler data has been adjusted to a 1.5 HC, 15 CO, 2.0 NOx base to make this base common to all data sources. Since no applicable model years were included in the Chrysler data, their estimates are considered applicable for all model years and will be enclosed in parentheses. The Study 1 and 2 estimates also were modified to remove the effects of reduced vehicle weight in future model years to make the EPA estimates consistent with the others. Though not specified by Chrysler, Ford, and GM, it was assumed from their discussions that constant vehicle weight was an assumption in Tables FE-5 to FE-7.

Tables FE-8 through FE-11 tend to show differences between the estimates of the vehicle manufacturers and those of Study 1 and Study 2. The Study 1 and 2 estimates are generally more optimistic than those of the vehicle manufacturers. These discrepancies between fuel economy estimates have historically been present and may continue to exist.

Table FE-9

Fuel Economy at 0.41 HC, 9 CO, 1.5 NOx

Model Year	Source	Estimated % Change in Fuel Economy	Technology Assumed Available
1978	Chrysler	NE	-
	Ford	-15 to -17	AIR/ESA/EEGR/OC
	GM	-11 to (7-15)	AIR/EGR/OC
	Study 1	NE	-
	Study 2	NE	-
1979	Chrysler	NE	-
	Ford	-11	AIR/ESA/EEGR/OC
	GM	NE	-
	Study 1	NE	-
	Study 2	NE	-
1980	Chrysler	NE	-
	Ford	-11	AIR/ESA/EEGR/OC
	GM	NE	-
	Study 1	NE	-
	Study 2	NE	-
1981	Chrysler	NE	-
	Ford	-4 to +1	AIR/EEC/3W/OC
	GM	NE	-
	Study 1	NE	-
	Study 2	NE	-

Table FE-10

Fuel Economy at 0.41 HC, 3.4 CO, 2.0 NOx

Model Year	Source	Estimated % Change in Fuel Economy	Technology Assumed Available
1979	Chrysler	(-6)	Proven Technology
	Ford	-8	ESA/EEGR/AIR/OC
	GM	NE	-
	Study 1	+1 to +11	FL/EEGR/ESA/AIR/IFM/OC/SC
	Study 2	+2 to +12	Study 1 + EAIR
1980	Chrysler	(-6)	Proven Technology
	Ford	-8	ESA/EEGR/AIR/OC
	GM	NE	-
	Study 1	+2 to +13	same
	Study 2	NE	-
1981	Chrysler	(-6)	Proven Technology
	Ford	-3 to +2	AIR/EEC/3W/OC
	GM	NE	-
	Study 1	+5 to +17	same
	Study 2	NE	-
1982	Chrysler	(-6)	Proven Technology
	Ford	NE	-
	GM	-10 to -20	AIR/EGR/OC
	Study 1	+9 to +21	same
	Study 2	+12 to +21	same

Table FE-11

Fuel Economy at 0.41 HC, 3.4 CO, 1.0 NOX

Model Year	Source	Estimated % Change in Fuel Economy	Technology Assumed Available
1981	Chrysler	(-12)	Proven Technology
	Ford	-6 to -1	AIR/OXC/3W/OC
	GM*	0 to -20	PBC/EGR/AIR/3W/ OC
	Study 1	+3 to +15	PL/EAIR/EEGR/ESA/IPW/SC/3W
	Study 2	+4 to +16	same as Study 1

* Model year not stated by GM but assumed to be 1981 as indicated by the Conference Committee Report.

The most important interpretation of the results in Tables FE-8 through FE-11 is the fact that as improved emission control technology is installed on vehicles, such as for 0.41 HC, 3.4 CO, 1.0 NOx in 1981, the fuel economy penalty estimates made by the manufacturers become almost insignificant (Ford says -1% with their best technology) or include a range that has no penalty (GM says 0 to -20%). This illustrates that estimates of the fuel economy impact of future emission standards are highly dependent on the technology that is assumed to be in production. The fuel economy penalties shown by the manufacturers at less stringent emission levels could be explained by their assumption of the use of emission control technology that may not be optimal for fuel economy at those emission levels.

4.1.3. Engine-Related Systems for Near Term Improvements in Fuel Economy

There are several engine-related approaches currently under development by the industry which appear to be capable of providing substantial improvements in vehicle fuel economy. These systems include improved EGR systems, intake and exhaust valve deactivation systems, turbocharged engines, electronic emission control systems, and fast burn systems.

Improved EGR Systems

Ford previously suggested that the switch to backpressure EGR would provide up to 1 MPG (not specified as urban or composite) improvement in fuel economy. Ford has now nearly completed the conversion, as have AMC, Oldsmobile, Cadillac, and Buick, but a number of prominent domestic manufacturers including Chrysler, Chevrolet, and Pontiac are still primarily using ported or venturi vacuum amplified EGR systems.

All of the big three domestic manufacturers have reported efforts on electronic EGR systems. Electronic EGR systems are expected to be even better than backpressure EGR. Only Ford has reported comparative data between similar vehicles using a new generation EGR system. The results shown in Table FE-12 were from similar 3500 pound IW vehicles using the 302 engine and an automatic transmission. These results compare the use of sonic EGR to backpressure EGR on advanced oxidation catalyst systems calibrated to 0.41 HC, 3.4 CO, 1.0 NOx. Neither EGR system in Table FE-12 was electronically controlled. Ford is known to be investigating both electronically controlled and pneumatically controlled sonic EGR systems. Ford reported these tests as "best effort results".

Table FE-12

A New Generation EGR System*

	75 FTP			
	HC	CO	NOx	MPG_U
Backpressure	.55	3.00	.77	10.5
Sonic	.21	1.58	.74	11.5

The sonic EGR system achieved better emissions in addition to the 10% improvements in urban fuel economy. The 10% may understate the fuel economy advantage of sonic EGR because of the large discrepancy in HC emissions between the two systems and because the data were reported in December of 1975. It must be assumed that considerable development has been conducted since then.

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* Ford Status Report, December 1975, page 183.

The only possible restrictions on spark advance at these emission levels for 3-way or oxidation catalyst systems are: 1) the HC emission standard and 2) octane requirement. If the spark advance is not at the octane restriction of the engine/drivetrain combination (which it is not in the case of the Ford vehicles here), then the spark can be advanced to accomodate higher HC emissions and improved fuel economy. NOx increases can be handled catalytically or by higher EGR rates which may also yield higher HC emissions which must be considered in the spark advance calibration.

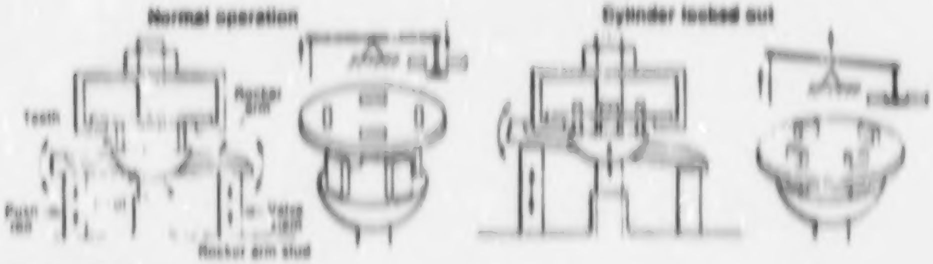
Intake/Exhaust Valve Deactivation Systems

The big three domestic auto manufacturers have all reported plans to evaluate or have already evaluated the Eaton-type valve deactivation system. The system is reported* to function as shown in Figure FR-2.

Ford efforts have concentrated on the 300 CID truck engine and prototype PROCO engines. The system deactivates 3 of 6 cylinders (3x6) on the 300 CID engine when power requirements are reduced, and deactivates both 2 and 4 cylinders of the V-8 PROCO (4x6x8). No vehicle testing was reported by Ford. General Motors reported the only available data in Table FR-13 for a 4x8 system on a 4000 pound IW vehicle with a 350 CID engine. Emission results were inconclusive, except for NOx reduction.

Figure FR-2

Probable Operation of Valve Deactivators



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* Machine Design, 21 October 1976.

Table FE-13

The Effect of the Valve Deactivation System

	HC	CO	NOx	MPG_u	MPG_h	MPG_c
Standard Vehicle 1	0.67	5.4	1.98	15.7	18.8	17.0
Vehicle 1 + Valve Deactivation	0.68	2.2	1.80	16.9	21.6	18.7
Standard Vehicle 2	0.55	5.0	1.85	15.3	18.9	16.7
Vehicle 2 + Valve Deactivation	0.76	9.0	1.05	16.7	20.8	18.4

Composite fuel economy showed about a 10% improvement.

A 2x4x6x8 configuration was reported* to be installed on a V-8 PROCO engine at Ford. This system on the PROCO was said to have "the potential to be 50% more economical on fuel than conventional engines are".

Turbocharged Engines

Turbochargers can be adapted to both spark ignition and compression ignition engines for the purpose of improving fuel economy. This is accomplished by maintaining the peak power output of a particular engine approximately constant by the addition of a turbocharger and a concomitant reduction in engine displacement. Alternately the engine displacement could remain constant and a substantial improvement in power output would be expected.

Five vehicle manufacturers are now believed to be considering the use of turbochargers on production vehicles. They are Saab, Daimler-Benz,

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* Ward's Engine Update, Vol. 3, Number 6, 18 March 1977.

Volkswagen, Ford, and General Motors. Very little was reported on the Ford and Volkswagen programs. The Daimler-Benz program is related to compression ignition engines and will not be considered further in this section as the Diesel application is probably designed for a power output increase and not a fuel economy improvement.

As shown in Figure FE-3 the Saab effort with their 2.0 litre engine and 3-way catalyst system was indicated to improved power output with even some losses in brake specific fuel consumption. An illustration of the Saab turbocharger is shown in Figure FE-4.

Compared to the Saab effort, the General Motors' effort is less oriented toward improved power output. The data in Table FE-14 show the changes in economy and performance of a prototype 1978 "A" car and a prototype 1978 "B" car when the turbocharger was adapted to a 231 CID, V-6 engine. All tests were reported to be at calibrations for 1.5 HC, 15 CO, 2.0 NOx. The "A" car line includes the Buick Century, Oldsmobile Cutlass, Pontiac LeMans, and Chevrolet Chevelle. The "B" car line includes the Buick LeSabre, Oldsmobile Delta 88, Pontiac, and Chevrolet.

The naturally aspirated vehicles in Table FE-14 are also of interest as they are some of the heavier vehicles in the GM line, and are all above the 1978 fuel economy level of 18.0.

Figure FE-3

Engine Dynamometer Testing of Turbocharged Saab Engines

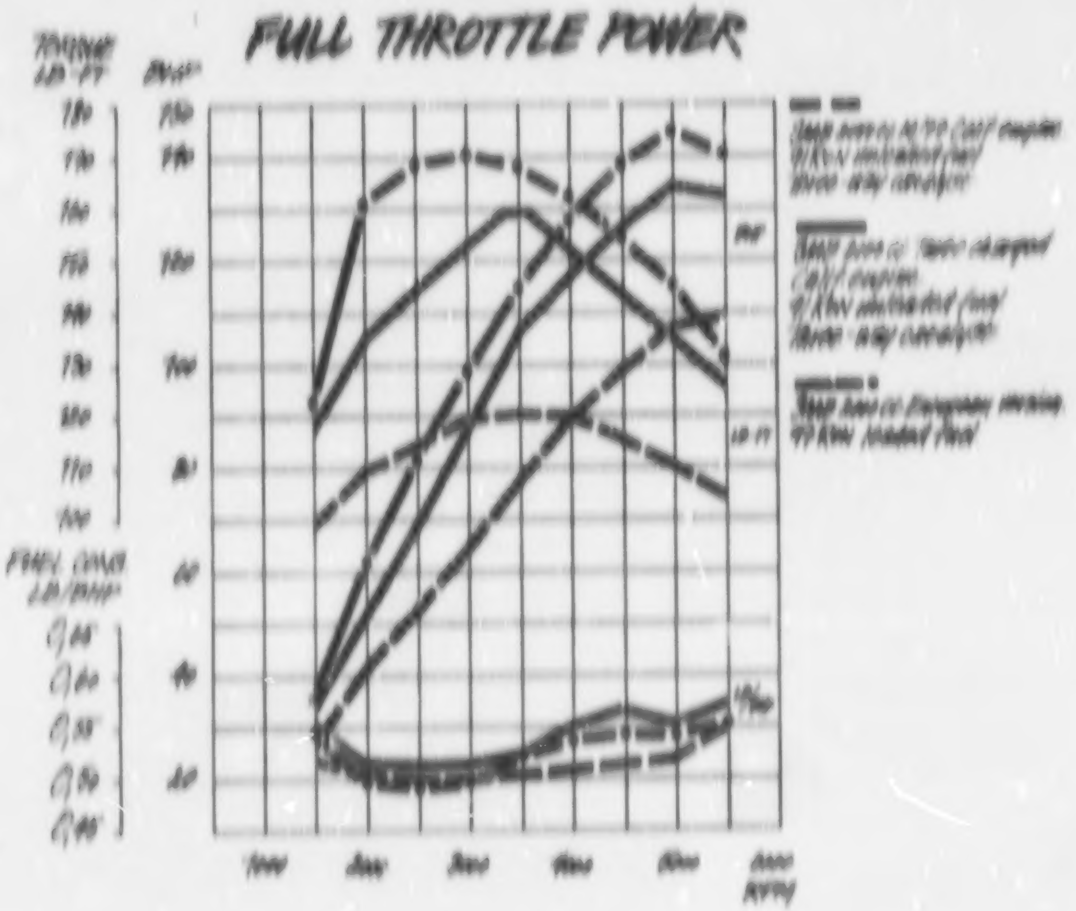

Figure III-4

SCHEMATIC FLOW TURBOCHARGER

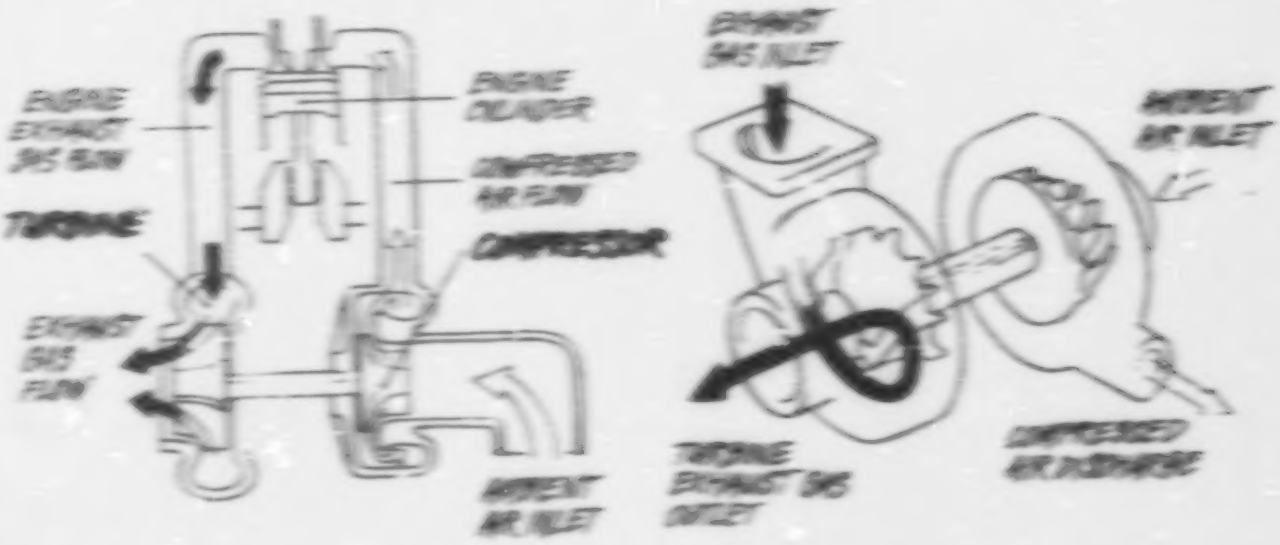
ENGINE EXHAUST GAS FLOW
TURBINE
EXHAUST GAS FLOW
ENGINE CYLINDER
COMPRESSED AIR FLOW
COMPRESSOR
AMBIENT AIR INLET
EXHAUST GAS INLET
AMBIENT AIR INLET
TURBINE EXHAUST GAS OUTLET
COMPRESSED AIR DISCHARGE

Table FE-14*

1978 Prototype GM Vehicles Using Oxidation Catalysts

Vehicle	Naturally Aspirated MPG**	 0-60 time (sec)	With Turbo MPG**	 0-60 time (sec)
"A"	20.6	15.7	22.0	12.4
"B"	18.7	18.0	20.5	14.0

** Not specified by GM as urban or composite

With the addition of the turbocharger, the improvement in fuel economy ranged from about 8-10% with improved vehicle acceleration. These performance and fuel economy gains are reported using the naturally aspirated 231 CID V-6 as the baseline. If the baseline engine were an engine of larger displacement equal in performance to the turbocharged V-6, the fuel economy gains would be expected to be even higher.

Electronic Control of Spark Advance (ESA)

The addition of electronic control of the spark advance could result in improved fuel economy, improved vehicle emissions, improved driveability, or some combination of modifications to all three. The actual changes in calibration of spark timing would determine the precise changes in emissions, economy, and driveability.

The results in Table FE-15 show two applications of electronic spark control in the 1977 certification program. All four vehicles are Oldsmobiles with 403 CID engines, automatic transmissions, and 2.73 axles at 5000 pounds inertia weight. In family 730PAUY the spark recalibration resulting from the use of ESA yielded considerably higher NOx emissions and about a 9% improvement in composite fuel economy. In family 730M4AU, CO emissions were increased somewhat and composite fuel economy was improved about 3%. Thus in both cases, the ESA system was not designed for improved emissions. The precise goals for the use of

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* GM Status Report, December 1976, page VII-133.

ESA on these two engine families could have been related to either driveability or fuel economy. The rather substantial improvement in fuel economy of the one family suggests that improved fuel economy was a primary goal in that application.

Table FE-15

The Addition of ESA to 1977 Oldsmobiles

Family	VIN	ESA	Without ESA	HC	CO	NOx	MPG_u	MPG_h	MPG_c
				----(with DF)---					
73OP4UY	7341F3		X	0.83	5.4	1.3	11.9	17.3	13.8
	7341F6	X		0.85	5.2	1.9	13.1	18.5	15.1
73OM4AU	7331C5		X	0.35	5.8	1.3	11.2	17.5	13.4
	7331C6	X		0.36	8.9	1.4	11.4	18.5	13.8

Feedback Air-Fuel Metering

Feedback air-fuel metering could enter production as either feedback carburetion (FBC), single-point fuel metering (SPFM), or multi-point fuel injection (FI). Though comparative data for these different systems on similar vehicles are not abundant (see Ford data in Section 7.1.3.), EPA believes that the use of FI + 3-way catalysts is currently being weighed against the use of FBC or SPFM + 3-way + oxidation catalysts + AIR at statutory HC and CO levels with NOx levels of 1.5 gm/mi or lower. The primary need for both AIR and the oxidation catalyst is for CO control. SPFM and FBC are suspected of having poorer engine out CO emissions. This suspicion is based on: 1) the observation that typical ±2 σ air-fuel control ranges over hot 505 (bag 3) tests range from about 0.5 to 0.7 for SPFM and FBC and about 0.18 to 0.3 for reasonably good FI systems (values much higher and lower have been seen for FI systems), 2) the inability to eliminate cylinder to cylinder distribution problems with both SPFM and FBC, and 3) inherently longer feedback system response time of SPFM and FBC.

Cylinder to cylinder air distribution problems can be controlled with FI systems by either injector matching or electronic compensation of the signal to the injector on electronic FI systems. Also the system response time of the FI system is better because fuel flow corrections can be made closer to the cylinder.

CO emissions out of the engine are highly dependent on air-fuel ratio and increase very rapidly as the air-fuel ratio goes richer than stoichiometry.

EPA technical staff believe that closed loop air-fuel metering may not be necessary on lighter inertia weight vehicles (less than about 3000 pounds IW) even at NOx levels of 1.0 or less with statutory HC and CO. The efforts of Nissan with their fast burn engine are the most illustrative of this fact. Ford efforts on oxidation catalyst vehicles in the Low NOx Fleet (3500 IW) further substantiate this. GM efforts show that these levels can be achieved at low mileage on vehicles up to 4500 pounds inertia weight when thermal reactor, electronic controls, plus oxidation catalyst systems are used; however, fuel economy objectives may not be as easy to attain with open loop air-fuel metering systems.

Ford efforts on air-fuel ratio perturbations show that fluctuations in air-fuel ratio may be valuable in certain applications. This work shows that the 3-way catalyst window can be widened by the addition of oxygen storage components to the 3-way catalyst and by introducing air-fuel ratio fluctuations of controlled amplitude and frequency. Some of the more successful Ford work has been concentrated around air-fuel fluctuations of ± 1 air-fuel ratio at 1 Hz frequency.

Near Stoichiometric Versus Lean Calibrations

The Ford Low NOx Fleet provides a reasonable comparison of stoichiometric air-fuel ratio calibrations versus lean air-fuel ratio calibrations for the same emission target. Both the stoichiometric and lean vehicles were calibrated to 0.41 HC, 3.4 CO, 1.0 NOx and used backpressure EGR and AIR. The stoichiometric systems used a 3-way plus oxidation catalyst emission control system, and the lean systems used oxidation catalysts. No advanced, electronic emission control systems were used. The average urban fuel economy results for the 3W + OC systems were about 40% higher than for the OC systems on these nearly identical vehicles. The spark calibrations of the 3W + OC vehicles appeared to be considerably more advanced and HC emissions out of the 3W + OC vehicles were considerably higher, though probably still adequate for a statutory NMHC standard. While the fuel economy of the OC vehicles could be adjusted upward to account for lower HC emissions, this adjustment probably would not make up the 4.5 MPG$_U$ differential (15.9 MPG$_U$ versus 11.4 MPG$_U$) between the 3W + OC and OC systems.

Knock Limit Control Systems

Only General Motors and Exxon Research and Engineering (under contract for EPA) are currently known to be evaluating such a system. The only known application of the system at GM is on their turbocharged V-6 for the 1978 model year. GM will apparently investigate an approach similar to Exxon's. The Exxon work is attempting to increase the compression ratio of an engine while retaining its ability to operate on 91 RON fuel.

The purpose of the system is to detect spark knock and if spark knock occurs, retard the spark timing until conditions permit the spark to be advanced. These systems have the potential to detect spark knock before it becomes audible to the driver. Prolonged knock at high air flow rates is potentially destructive to the engine of the vehicle and must be avoided.

This system could have several applications. In addition to the potential uses mentioned, the system could be used for attaining more spark advance at a constant compression ratio with 91 RON fuel or attaining the ability to operate on fuel of less than 91 RON with the same compression ratio. Since GM has not reported data that would isolate the effect of the knock control system, the Exxon efforts will be discussed. A schematic of the GM system is shown in Figure FE-5.

The vehicle being used at Exxon is a 1975 California Nova with a 350 CID engine and an automatic transmission at 4000 pounds inertia weight. The knock limit control system has been installed on the vehicle, however, emissions from the vehicle have not yet been measured with the system operational. The emissions are not expected to change much from those without the knock limiter system as the vehicle is wide open throttle (WOT) knock limited and WOT conditions will not be encountered on the FTP. Octane requirement testing in the laboratory on an engine dynamometer has suggested that a gain in compression ratio of one full number (from 8.0:1 actual to 9.0:1 actual compression ratio) can be attained. This assumes that the octane requirement increase will be the same at 9.0:1 as at 8.0:1. Fuel economy and emission results of the vehicle at the two compression ratios without the knock limit control system are shown in Table FE-16.

Table FE-16

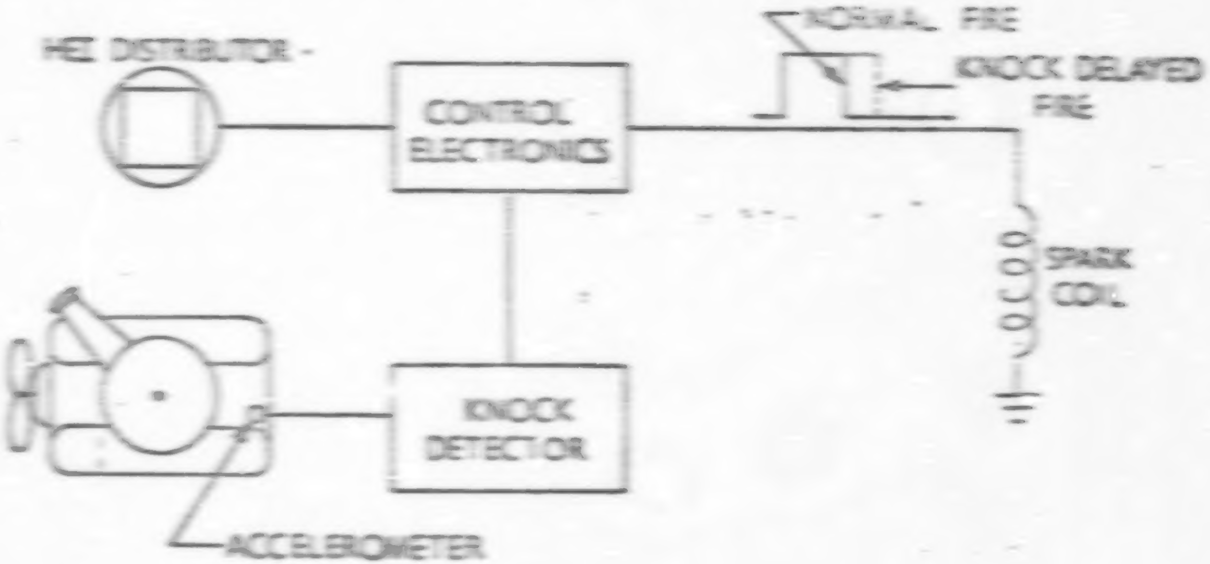
Effect of a Change in Compression Ratio from 8:1 to 9:1

Compression	#	-----75 FTP------			------Fuel Economy------		
Ratio	Tests	HC	CO	NOx	MPG_u	MPG_h	MPG_c
8.0:1	4	0.54	5.98	1.67	11.4	16.5	13.2
9.0:1	4	0.62	8.11	2.24	12.3	18.1	14.4

About a 9% increase in composite fuel economy is shown for the increase in compression ratio. An emission penalty was initially noted, however, when the EGR system was changed from ported to backpressure EGR (and recalibrated) and the choke was leaned one notch, the emissions then

Figure III-5

KNOCK LIMIT CONTROL


HEI DISTRIBUTOR -
CONTROL ELECTRONICS
NORMAL FIRE
KNOCK DELAYED FIRE
SPARK COIL
KNOCK DETECTOR
ACCELEROMETER

were 0.51 HC, 3.92 CO, 1.72 NOx (3 test average) and fuel economy was further improved to 14.8 MPG_c.

GM efforts on a similar vehicle with a compression ratio change from 8.3:1 to 9.2:1 show about an 8% improvement in fuel economy, but suggest* that a more universal relationship is about 6% increase in fuel economy for each number of compression ratio increase.

Other Electronic Controls

General Motors reported data on a single vehicle which was calibrated for 0.41 HC, 3.4 CO, 1.0 NOx using electronic control of 1) spark timing, 2) EGR, 3) cold enrichment, and 4) idle speed. The 350 CID Chevrolet was also equipped with thermal reactors and a production oxidation catalyst. The emission and fuel economy results of this vehicle and some 1977 Federal certification vehicles of similar IW and with the same displacement engine are shown Table FE-17.

Table FE-17

Emission and Fuel Economy Gains with Electronic Controls

			75 FTP			Fuel Economy		
Vehicle	Engine	IW	HC§	CO§	NOx§	MPG_u	MPG_h	MPG_c
Electronic Control	350	4000	0.25	1.20	0.75	13.2	18.6	15.2
Cert # 716OF5	350	4000	0.29	3.80	1.32	14.9	20.1	16.9
Cert # 716OF5	350	4000	0.28	2.40	1.46	14.1	18.1	15.7
Cert # 716BF6	350	4000	0.53	2.80	1.68	12.7	15.9	14.0

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§ 4K values for cert cars, without DF.

While the electronically controlled vehicle shows substantially improved emission control capability at low mileage, its fuel economy is also less than two of the three 1977 Federal certification vehicles. No similar oxidation catalyst equipped vehicles without the electronics which were calibrated to similar emission levels could be found.

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* James J. Gumbleton, et al., "Effect of Energy and Emission Constraints on Compression Ratio," SAE Paper 760826.

It should be noted that this testing was done by GM on an oxidation catalyst system instead of a 3-way catalyst system. GM indicated that this system was considered so that they will have system ready for production in case their 3-way catalyst systems encounter problems. The fuel economy of a 3-way catalyst vehicle using similar technology may be considerably higher than the fuel economy of this vehicle, as the Ford Low NOx Fleet results indicate.

Fast Burn

The Nissan fast burn system (see Nissan section 7.3.9.) represents an attractive system at statutory emission levels due to its excellent fuel economy performance. The key components to the system are one additional spark plug in each modified combustion chamber, EGR, and an oxidation catalyst (similar to many current production vehicles). The EGR rates are extremely high for a gasoline engine, but their use permits attainment of statutory NOx levels at low mileage. The development of the system has been very rapid, and the testing very limited. The results shown in Table FE-18 represent some of the best results reported on the single vehicle using this system.

Table FE-18

Nissan Fast Burn System
2750 IW

HC	CO	NOx	MPG_u	MPG_h	MPG_c
0.22	2.09	0.38	22.2	33.1	26.1
0.24	2.01	0.37	22.6	33.4	26.4

The fuel economy results are within the range of the similar Nissan 1977 Federal emission data and durability vehicles.

4.1.4. Other Engine-Related Systems for Improving Fuel Economy

The engine-related fuel economy/emissions control systems discussed in Section 4.1.3. do not cover some of the advanced emission control technology discussed in previous years' reports. These approaches are still potential candidates for use if, for example, a manufacturer's fuel economy performance is limited by HC control, rather than octane considerations.

These technical approaches include: (1) heat conservation (port liners, insulated combustion chambers, thermal reactors, insulated exhaust manifolds, insulated exhaust pipes), (2) controlled air injection systems, (3) improved warm-up emission control (start catalysts, EFE and Super EFE, charcoal storage, vaporizing chokes, on-board distillers, catalysts with improved light-off performance, heated fuel injection nozzles, electrically modulated chokes), (4) improved warmed-up emission control (larger catalyst volumes, higher noble metal loadings, improved resistance to thermal and chemical deactivation), and (5) improved fuel metering (electronic accelerator pump, fuel shutoff on deceleration, improved intake air-fuel mixture distribution, etc.).

All of the above approaches can be used to reduce emissions and therefore have the potential to be part of an emission control system that could be applied to a vehicle calibrated for best fuel economy. Some vehicles may not need any of these advanced emission control techniques, but all of these technical approaches are considered by EPA to be available to the manufacturers, should they need additional emission control for improved fuel economy and/or driveability.

4.1.5. Other Engines

Several alternate engine concepts which have the potential for improved fuel economy and low NOx emissions are being considered by the industry.

These options include Diesel engines, the Ford PROCO engine, and the Honda CVCC engine. The current fuel economy and emissions performance of vehicles using these alternate engines is shown in Table FE-19. The fuel economy comparison is made between the alternate engine and the sales weighted fuel economy of all 1977 Federal certification vehicles at the same inertia weight. This is done to compare the fuel economy of vehicles of the same weight. Generally, the performance characteristics of the vehicles equipped with these prototype alternate engines are not reported, so making a comparison based on equal performance is not possible. In many cases, the performance of the vehicles with the alternate engines is expected to be somewhat poorer than the average performance of the vehicles to which they are compared. Therefore, the results shown on Table FE-19 may be inflated somewhat.

4.1.6. Other Fuel Economy Improvements

The fuel economy section of this report has concentrated on engine-related fuel economy effects, since these are most directly involved in emissions/fuel economy interactions. It should be noted, however, that fuel economy is influenced by several other factors not treated in detail in this report. Among these factors are: vehicle weight effects, drivetrain effects, power-to-weight ratio effects, accessory drive effects, rolling resistance, aerodynamic effects, etc.

Of the above-mentioned factors that influence fuel economy, some are expected to have directionally positive impacts on the capability to control emissions. These factors are those that tend to reduce the exhaust volume generated by the vehicle during the test. These factors are reduced vehicle weight, improvements in accessory drives, improvements in rolling resistance (tires, lubricants, engine frictions, drivetrain friction), and aerodynamic effects. These factors especially reduced vehicle weight, can have a much greater impact on fuel economy than most of the engine-related topics discussed in this report.

Table FE-19

Alternate Engines with Good Fuel Economy

Manufacturer	Engine	IW	HC	CO	NOx	MPG_u	MPG_h	MPG_c	Sales Weighted MPG_c in IW Class in 1977 Certification	% Increase MPG_c *
Honda	CVCC	2000	1.4	6.2	1.4	41	54	46	35.9	28
Ford	PROCO	5000	0.22	0.1	0.78	15.5	22.7	18.1	14.4	26
Daimler-Benz	Diesel	3500	0.37	1.2	1.43	24.8	33.5	28.1	20.5	37
Peugeot	Diesel	3500	1.04	2.1	0.91	27.7	34.7	30.1	20.5	47
GM	Diesel	4500	0.85	1.8	1.50	20.8	29.7	24.0	16.7	44
VW	Diesel	2250	0.78	1.0	0.61	50.4	64.6	55.8	31.8	75

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* Increase over sales weighted fuel economy of all 1977 Federal Certification vehicles at the same IW as shown for alternate engines. Emission data do not include DF.

The impacts on emissions of drivetrain improvements and power-to-weight ratio changes are not well known at this time. Improvements in both areas yield fuel economy gains, because the engine is operating "harder" (at a higher load factor) during the test. Operation at a higher load factor could yield higher engine-out emissions for NOx. However, catalyst light-off performance and EGR tolerance are expected to improve with higher load factors, so the actual result could be an improvement in emissions. More information is required in this area before more specific conclusions can be drawn.

4.2. Cost

The Cost Section in this year's status report represents a preliminary effort to obtain cost information. Further study is currently in progress to provide this information with greater accuracy and in much greater depth and detail than has been reported in the past. These detailed findings will be the subject of a separate report.

As has been the case in previous years, the majority of manufacturers submitted little or no cost information in their submissions to EPA. A few manufacturers, among whom were AMC, Toyo Kogyo, and Saab, provided information in somewhat better detail than did other manufacturers.

As an example of the range of the types of responses concerning emission control system cost information submitted by the manufacturers Attachment Cost-1 and Attachment Cost-2 (which can be found at the end of this section) have been prepared. Attachment Cost-1 is AMC's response, and Attachment Cost-2 is GM's response.

Estimations of the likely increase in vehicle cost or "sticker" price associated with meeting a particular emission level begin by assuming what control system or range of control systems are necessary to attain that emission level. These control systems must then be broken down into the various components which comprise each system. Next, the types of materials, their amount or weight, and their cost per unit weight must be identified and the costs summed together to get a total cost of materials for each component. Depending on the level of knowledge available, there are generally two basic methods which may then be used. (See Figure Cost-1.) The first (Method #1) simply employs a factor to get from the cost of materials used to its contribution to "sticker" price. This method is used where little is known as to the other elements of cost which make up the final cost to the consumer. The other method (Method #2) is much more detailed and involves basically three levels: the plant, the corporation, and the dealer.

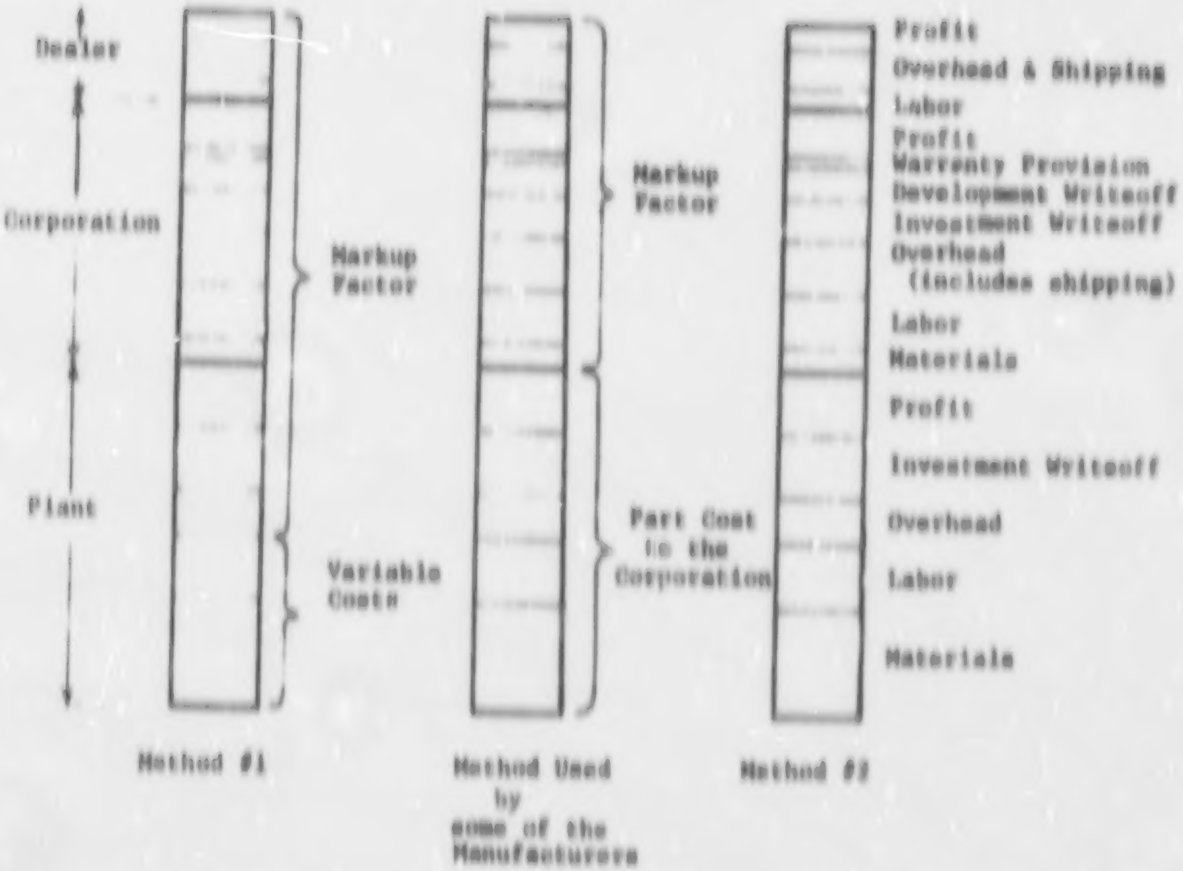
Method #2 involves a detailed estimate of several influencing factors: materials, labor, overhead, investment writeoff, development writeoff, warranty provisions, shipping charges, profit, etc. These factors are not the same for each automobile company and may vary with the specific type of emission control component. The length of time necessary to investigate each of these elements precluded making a detailed EPA cost estimate of this type for this report.

The following two tables (Table Cost-1 and Table Cost-2) present the ranges of costs for specific emission control components and for systems to be used at various emission levels as reported by the manufacturers. EPA's estimates are to be included in a separate report as discussed above. In Table Cost-1, estimates for many of the emission control components were not provided in this year's submissions to EPA thus last year's estimates as reported by the manufacturers are presented and are noted with an asterisk.

Table Cost-2 shows "sticker" estimates, as provided by the manufacturers, of the cost ranges to meet various emission standards relative to a specific base year/emission standard.

Figure Cost-1

Elements of Cost Estimates for Various Methodologies



Dealer
Corporation
Plant
Markup Factor
Variable Costs
Method #1
Markup Factor
Part Cost to the Corporation
Method Used by some of the Manufacturers
Profit
Overhead & Shipping
Labor
Profit
Warranty Provision
Development Writeoff
Investment Writeoff
Overhead (includes shipping)
Labor
Materials
Profit
Investment Writeoff
Overhead
Labor
Materials
Method #2

Table Cost-1

Emission Control Component Retail "Sticker" Costs

Item/Component/Subsystem	Range of Manufacturer's Estimate, Dollars
PCV Valve	2 to 3*
Anti-Dieseling Solenoid	2 to 6*
Air Injection System	40 to 50
Air Switching System	15 to 30*
Reed Valve Air System	11
EGR System	10 to 40
Pelleted Ox. Cat. (each)	16 to 150
Monolithic Ox. Cat. (each)	66 to 153*
Pelleted Red. Cat. (each)	72 to 150*
Monolithic Red. Cat. (each)	90 to 157*
Monolithic Start Cat. (each)	49 to 66
Monolithic 3-Way Cat. (each)	55 to 137
Metallic Red. Cat. (each)	100*
Oxygen Sensor	14 to 20
Electronic Fuel Metering	100 to 137
Thermal Reactor (each)	4 to 86*
Port Liners (each)	1*
Quick Heat Manifold	N.R.
Super EFE	N.R.
Electric Choke	4 to 9*
High Energy Ignition	27 to 116*
Improved Exhaust System	30 to 40*
Insulated Exhaust Pipe	N.R.
Carb Mods for Altitude Comp.	N.R.
Carb Mods for Feedback Control	5 to 10% over cost of similar, non feedback carb
Electronic Control Unit	68
Air Modulated System	N.R.
Inlet Air Sensor	N.R.
Engine Load Sensor	N.R.

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* These cost figures were not reported in this year's submission thus the figures shown are last year's values as reported by the manufacturers.

N.R. means not reported this year or last year.

Table Cost-3

Emission Control System Retail "Sticker" Cost Increases to Meet Various Standards

Emission Standards HC/CO/NOx (year)	Range of Manufacturer Estimates Dollars	Base Year
1.5/15/2.0 ('78 Fed)	-20 to 120	'77 Fed
1.5/15/2.0 ('78 Fed)	45 to 60	'74 Fed
0.9/9/2.0 ('79 Fed)	not requested	
0.41/9/1.5 ('77-'79 CA)	53 to 136	'77 Fed
0.41/9/1.5 ('78 CA)	-70 to -50	'77 CA
0.41/9/1.5 ('78 Fed)	0 to 237	'77 Fed
0.41/9/1.5 ('78 Fed)	339 to 345	'74 Fed
0.41/3.4/2.0 ('79-'80)	0 to 380	'77 Fed
0.41/3.4/2.0 ('79-'81 Fed)	339	'74 Fed
0.41/3.4/1.0 ('81 Fed)	113 to 376	'77 Fed
0.41/3.4/1.0 (?)	0 to 470	'77 Fed
0.41/3.4/1.0 ('79-'81 Fed)	339	'74 Fed
0.41/3.4/1.0 ('79-'80 Fed)	32	'77 Fed
0.41/3.4/0.4 ('8x or ? Fed)	423 to 538	'77 Fed
0.41/3.4/0.4 ('82 CA)	186	'77 CA

Attachment Cost-1

AMC Cost Information
from AMC Status Report

V. COST INFORMATION

A. First Cost

The estimated costs of the systems discussed in this report are contained in tables 1 through 7. In many of the systems discussed the accuracy of the estimates may be questionable since designs have not been finalized and supplier cost data are not available. Only the 1978 model cost data can be considered reasonably accurate.

B. Operating Cost

On tables 8 and 9 we have listed the estimated operating costs of the systems discussed. On table 10 we list catalytic converter maintenance costs. In the case of MPG data for 1978 systems we have used 1977 model year MPG label information since the systems are essentially carryover. Projections for systems beyond 1978 are difficult since compliance with emissions standards have not been achieved and therefore specific MPG data are not available.

TABLE I

[illegible]
ESTIMATED [illegible] COST PENALTIES FOR
[illegible] DESIGNED TO MEET
1.5 HC, [illegible], 2 NOx [illegible] STANDARDS

[illegible] 1967 MODEL

	4-Cylinder				6-Cylinder				8-Cylinder	
	(1)		(2)		(1)		(2)		(1)	(2)
	Man	Auto	Man	Auto	Man	Auto	Man	Auto	Auto	Auto
Induction System (outside air)					2.41	2.41	2.55	2.55	3.88	4.56
Evaporative Control System										
1. 4-port canister	.46	.46	.54	.54	.46	.46	.54	.54	.46	.54
2. Carburetor-mechanical bowl vent					1.44	1.69	1.69	1.69	2.01	2.36
3. Additional hoses, etc.					.55	.55	1.01	1.01	.86	1.01
4. Auxiliary fuel trap in bowl vent line									1.15	1.35
Ignition System Revised (Fuel Distributor)					10.19	10.19	11.99	11.99	10.19	11.99
	.46	.46	.54	.54	15.38	15.35	16.08	16.28	18.55	21.81

(1) Est. wholesale (factory) price
(2) Est. [illegible] (retail) price

[illegible]
[illegible]
[illegible] FOR
SYSTEMS AS CURRENTLY DESIGNED TO MEET
.41 HC, 9 CO, 1.5 NOx EMISSIONS STANDARDS
EPA TEST PROCEDURES

1976 MODEL VERSUS 1977 MODEL

	4-Cylinder				6-Cylinder				8-Cylinder	
	(1)		(2)		(1)		(2)		(1)	(2)
	Man	Auto	Man	Auto	Man	Auto	Man	Auto	Auto	Auto
Induction System (outside air)					2.43	2.43	2.85	2.85	3.88	4.56
Evaporative Control System										
1. 4-port canister	.46	.46	.54	.54	.46	.46	.54	.54	.46	.54
2. Carburetor-mechanical bowl vent					1.44	1.44	1.69	1.69	2.01	2.36
3. Additional hoses, etc.					.86	.86	1.01	1.01	.86	1.01
4. Auxiliary fuel trap in bowl vent line									1.24	1.46
Air Injection System Revision	5.52	5.52	6.49	6.49						
Catalyst										
Underfloor		c/o 1977					c/o 1977		97.75	115.00
Pre-catalyst					41.40	41.40	48.71	48.71	82.60	97.41
Exhaust System Revision					1.15	1.15	1.35	1.35	2.30	2.71
Ignition System Revisions					10.19	10.19	11.99	11.99	10.19	11.95
	5.98	5.98	7.03	7.03	57.93	57.93	68.14	68.14	201.49	237.06

(1) Est. wholesale (dealer) price
(2) Est. average (sticker) price

TABLE [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

1979/80 MODEL VERSUS 1978 MODEL

	4-Cylinder (1) Man	4-Cylinder (1) Auto	4-Cylinder (2) Man	4-Cylinder (2) Auto	6-Cylinder (1) Man	6-Cylinder (1) Auto	6-Cylinder (2) Man	6-Cylinder (2) Auto	8-Cylinder (1) Auto	8-Cylinder (2) Auto
Ignition System										
Microprocessor (spark control)					58.37	58.37	68.67	68.67	58.37	68.67
Sensors Misc. electronic cables, etc.					34.50	34.50	40.59	40.59	34.50	40.59
Distributor Electronic Ignition	20.12	20.12	23.67	23.67						
Delete EGR System	(8.20)	(8.20)	(9.65)	(9.65)	(8.20)	(8.20)	(9.65)	(9.65)		
Delete Air Guard System	(33.87)	(33.87)	(39.85)	(39.85)	(33.87)	(33.87)	(39.85)	(39.85)		
Closed Loop Fuel Control	27.46	27.46	32.31	32.31						
Oxygen Sensor	11.50	11.50	13.53	13.53						
Catalyst:										
Improved Underfloor (delete)	(97.75)	(97.75)	(115.00)	(115.00)						
3-Way Catalyst	116.31	116.31	136.84	136.84						
	35.57	35.57	41.85	41.85	50.80	50.80	59.76	59.76	92.87	109.26

(1) Est. wholesale (dealer) price
(2) Est. average (retailer) price

[illegible]
[illegible]
[illegible]
[illegible]
[illegible]

1979/80 MODEL CHANGES 1979 MDL.

	6-Cylinder			
	(1)		(2)	
	Man	Auto	Man	Auto
E.C.S. System	4.43	4.43	5.21	5.21
Ignition System				
Distributor revisions				
Feedback fuel controlled carburetor	15.53	15.53	18.27	18.27
Oxygen sensor	11.94	11.94	14.05	14.05
Exhaust system modifications	1.15	1.15	1.35	1.35
New 3-way catalyst	116.31	116.31	136.84	136.84
Delete				
Oxidizing catalyst	(97.75)	(97.75)	(115.00)	(115.00)
EGR system	(8.20)	(8.20)	(9.65)	(9.65)
Air guard system	(33.87)	(33.87)	(39.85)	(39.85)
	9.54	9.54	11.22	11.22

(1) Est. wholesale (dealer) price
(2) Est. average (sticker) price

TABLE 4-[illegible]
[illegible]
[illegible] COST (DEALER/STICKER) [illegible] FOR
EMISSION CONTROL SYSTEMS DESIGNED TO MEET
.41 HC, 3.4 CO, 1.0 NOx EMISSION STANDARDS
[illegible]

1979/80 MODEL VERSUS 1978 MODEL

	6-Cylinder			
	(1)		(2)	
	Man	Auto	Man	Auto
T.C.S. System	4.43	4.43	5.21	5.21
Ignition System				
Distributor revisions				
Revised air guard	29.62	29.62	34.85	34.85
Feedback fuel controlled carburetor	15.53	15.53	18.27	18.27
Oxygen sensor	11.94	11.94	14.05	14.05
Exhaust system modifications	1.15	1.15	1.35	1.35
Catalyst System				
New 3-way catalyst with added oxidizing catalyst	172.50	172.50	202.94	202.94
Oxidizing catalyst (delete)	(97.75)	(97.75)	(115.00)	(115.00)
Delete				
EGR system	(8.20)	(8.20)	(9.65)	(9.65)
Air guard system	(33.87)	(33.87)	(39.85)	(39.85)
	95.35	95.35	112.17	112.17

(1) Est. wholesale (dealer) price
(2) Est. average (sticker) price

TABLE 6
AMERICAN MOTORS CORPORATION
ESTIMATED FUTURE DEALER/CUSTOMER COST PENALTIES FOR EMISSIONS HARDWARE REQUIRED TO MEET .41 HC, 3.4 CO, 1.0 NOx EMISSIONS STANDARDS

1981 MODEL VERSUS 1979/80 MODEL (FIRST CHOICE)

	4-CYLINDER				6-CYLINDER			
	(1)		(2)		(1)		(2)	
	Man	Auto	Man	Auto	Man	Auto	Man	Auto
1. Feedback Fuel Control Carburetor (includes oxygen sensor, etc.)					115.87	115.87	136.32	136.32
2. Oxygen Sensor								
3. New 3-way Catalyst (delete present)					172.50 (97.75)	172.50 (97.75)	202.94 (115.00)	202.94 (115.00)
4. Exhaust System Modifications	1.15	1.15	1.35	1.35	1.15	1.15	1.35	1.35
5. Other changes for distributor control, digital microprocessor control	57.50	57.50	67.65	67.65	6.19	6.19	7.28	7.28
6. Distributor revisions to provide for No. 5 above	36.80	36.80	43.29	43.29	2.30	2.30	2.71	2.71
7. Improved air cleaner and carburetor sealing	17.69	17.69	20.81	20.81	17.69	17.69	20.81	20.81
8. Programmed air injection (new microprocessor and other)	Not on 4-cylinder engine				29.62 63.25	29.62 63.25	34.85 74.41	34.85 74.41
Delete microprocessor					(57.50)	(57.50)	(67.65)	(67.65)
	113.14	113.14	133.10	133.10	253.12	253.12	298.02	298.02

(1) Est. wholesale (dealer) price
(2) Est. average (customer) price

TABLE 7
AMERICAN MOTORS CORPORATION
ESTIMATED FUTURE DEALER/CUSTOMER COST PENALTIES FOR EMISSIONS HARDWARE DESIGNED TO MEET .41 HC, 3.4 CO, .4 NOx EMISSIONS STANDARDS

[illegible] MODEL VERSUS 1981 MODEL

	4-CYLINDER				6-CYLINDER			
	(1)		(2)		(1)		(2)	
	Man	Auto	Man	Auto	Man	Auto	Man	Auto
Induction System,								
Carburetor								
Fuel Injection					116.75	116.75	137.35	137.35
Exhaust System Revisions								
Ignition System Revisions								
Programmed EGR					23.44	23.44	27.58	27.58
Air Injection Revisions								
Catalyst System Upgrading								
Exhaust System Revisions								
					140.19	140.19	164.93	164.93

(1) Est. wholesale (dealer) price
(2) Est. average (sticker) price

TABLE 8

OPERATING COSTS - DOLLARS/50,000 MILES

	1973	1978	1978 (1977 Calif. Stds.)	1979/80	1981 198X
Fuel Costs					NA
6-cyl. compact 3500 lb I. W.	$1190	$1711	$1912	$1625	
V-8 full size 4500 lb I. W.	$1800	$2167	$2500	$1912*	
Maintenance Costs					NA
6-cyl. compact oil, filter, coolant & emission control system Total	$ 223.02	$ 184.15	$ 184.15	$ 182.77	
V-8 full size oil, filter, coolant & emission control system Total	$ 258.69	$ 209.90	$ 209.90	$ 209.90	
Total of itemized operating costs --					NA
6-cyl. compact	$1413.02	$1895.15	$2096.15	$1807.77	
V-8 full size	$2058.69	$2376.90	$2709.90	$2121.90	

*compact car @ 4000 lb I. W.

Assumed fuel costs $.65/gal. ($.45/gal. in 1973)

Assumed MPG
1973 - from previous 1975 year AM report.

1978 - Use 1977 EPA labeling data (combined MPG) - 6-cyl. compact 19 MPG
V-8 full size 15 MPG

1978 49-state with California standards - same as 1978 California systems
1977 EPA California labeling data (combined MPG) 6-cyl. compact 17 MPG
V-8 full size 13 MPG

1979/80 - based on 1980 legislated fleet requirement of 20 MPG - 6 cyl. compact 20 MPG
V-8 compact 17 MPG

1981 & 198X - not available

All costs based on 1976 dollars.

TABLE 9

MAINTENANCE COSTS (Dollars/50,000 Miles)
(Not including catalytic converters)

	1978 (1)			1978 (1) (California '77 Stds.)			1979-80 (2)		
	Parts	Labor	Total	Parts	Labor	Total	Parts	Labor	Total
6-Cyl.	$126.19	$ 57.96	$184.15	$126.19	$ 57.96	$184.15	$126.19	$ 56.58	$182.77
V-8	$140.90	$ 69.00	$209.90	$140.90	$ 69.00	$209.90	$140.90	$ 69.00	$209.90

Maintenance schedules and costs for 1979-80 are estimates.

Maintenance schedules and costs for 1981 and 198X are not available.

(1) See 50,000 mile maintenance schedule on page 11

(2) See 50,000 mile maintenance schedules on pages 12 and 13.

Cost indicated are owner costs.

TABLE 10

CATALYTIC CONVERTER MAINTENANCE

1978 Model Year - no maintenance required for first 50,000 miles.

1978 Model Year (1977 California standards) - no maintenance planned for first 50,000 miles.

1979-80 - No maintenance planned for first 50,000 miles.

1981 - 198X - No maintenance information available.

CATALYTIC CONVERTER MAINTENANCE (If Required)

1978 Model Year 1.5 HC, 15 CO, 2 NOx

pellet change, single converter 6-cyl. & 8-cyl.

1978 Model Year .41 HC, 9 CO, 1-1/2 NOx

pellet change 6-cyl. 1 converter, V-8 2 converters

new warm up converter 6-cyl. 1 converter, V-8 2 converters

1979-80 Model Years .41 HC, 3.4 CO, 2 NOx

pellet change single converter 6-cyl. & 8-cyl.

		1978 (.41, 9, 1-1/2)		
	1978	6-cyl.	V-8	1979-1980
pellet cost	$72.75	$ 72.75	$145.50	$72.75
pre-converter cost	--	$113.50	$227.00	--
labor cost	$ 8.28	$ 16.56	$ 22.09	$ 8.28
Total	$81.03	$202.81	$394.59	$81.03

Costs indicated are owner costs.

Attachment Cost-2

GM Cost Information
from GM Status Report

XI. COST

Listed below are costs to the consumer estimates applicable to the emission control systems described in previous sections of this report. It should be recognized that most of the hardware components contained in these systems are still in the development stage and there are no manufacturing plans or volumes available upon which to base a formal cost estimate. Therefore, these cost estimates represent our best estimates as to the effect on vehicle prices, under these limitations. It must be recognized, however, that since development work is still in progress, significant variances between this estimate and the ultimate cost can occur.

First Cost

Advanced GM Exhaust Emission Control System
Estimated Cost to the Consumer
Over Current 1977 Systems

	Cost to the Consumer $
Air Injection Reactor	25
Three-Way Converter Closed Loop System	70 - 110
Dual Converter System	190 - 230

It should be noted that the three-way converter and dual converter systems comprehend the usage of rhodium as a catalytic agent. Our estimates attempt to allow for various price and usage requirements of both rhodium and platinum. This is mainly the reason for the cost ranges associated with these systems. Due to the many ramifications of the rhodium situation supply and price (as previously discussed in this report) even this wide range is tenuous.

Maintenance Cost

At this time, it has not been determined what additional maintenance would be required. However, it is likely that the oxygen sensor will have to be replaced two or three times within the 50,000 mile limitation at an estimated additional cost of $15-$20 per replacement. As yet, GM has not demonstrated the durability of the three-way converter over the required 50,000 miles. In view of the aforementioned rhodium complexity, the bead replacement cost of the three-way catalyst is estimated to be in the area of $60-$100.

FE-1078
Environmental Activities Staff
General Motors Corporation
General Motors Technical Center
Warren, Michigan 48090

March 15, 1977

John P. DeKany, Director
Emission Control Technology Division
Environmental Protection Agency
2565 Plymouth Road
Ann Arbor, Michigan 48105

Dear Mr. DeKany:

This letter is in reply to your request for additional comments on emission control system component costs. Our comments are in the form of a review of pp. 4-17 to 4-21 from your report to the Administrator, "Automobile Emission Control--The Current Status and Development Trends As of March 1976." These comments are provided in addition to our previous submissions FE-1047 (February 10, 1977) and FE-1055 (February 18, 1977), responding to questions you and your staff raised regarding our 1976 emission control progress report.

If I can be of further assistance, please call me at 575-1269.

Gerald J. Barnes
Gerald J. Barnes
Automotive Emission Control

GJB/rmn/th/158

Attachment

General Motors Comments on EPA Cost Analysis

Statement on Page 4-17 - "Unfortunately, as has been the case in the past, the responses on cost from most manufacturers were not wholly responsive to the request from EPA on cost information. Some manufacturers submitted nothing, most submitted inadequately substantiated information ..."

Comment

The EPA cost request involved a level of detail that was not available. For instance, the Corporation is developing a Closed Loop control 3-way catalyst system. This is still in the development state and the cost estimates available are "best guess" only and are not based on formal cost estimating procedures. At this point, it would be meaningless to try to estimate what emission control devices would go on our various product lines and to report the fraction of each product line that require specific devices at various emission control levels.

Any GM speculation as to the equipment and cost tailored to our product lines would indicate a level of sophistication that does not exist for this technology at this time.

Table 4-12

This table depicts a methodology for estimating emission control hardware costs based on ratios of various elements of consumer cost. That this methodology should be developed is understandable in light of the EPA's need for cost estimates to perform economic impact studies. However, the data generated by this methodology can differ significantly from manufacturer's estimates, and when studies are published, based on these estimates, they should be highly qualified. For instance, the methodology used to estimate cost of a catalytic converter would not necessarily be valid for air/fuel ratio control systems.

Table 4-11

This is a listing of emission control hardware cost to the consumer estimates. This listing reflects a range of manufacturers estimates and EPA estimates.

General Motors estimated consumer costs, where available, are generally at the lower bound of the manufacturer's cost ranges.

It is difficult to understand why some of the EPA estimates reflect an upper range estimate lower than the bottom of the manufacturer's range. Perhaps one reason might be the fact that the manufacturer's estimates reflect associated component costs. For example, GM estimates the Air Injection Reactor System at $15 cost to the consumer. EPA's estimate is $10-$20. It is conceivable that the difference is the $6-$8 estimated mounting provision and plumbing included by GM. If we were estimating an air pump only, we would be in agreement with EPA.

Statement on Page 4-21 - "It is probably most appropriate to allocate to emission control a dollar figure near to the lower bound cost estimates, and to allocate to fuel economy improvements the difference between the higher and lower cost elements."

Comment

The purpose of this segregation is not clear. None of the emission control devices on our vehicles are installed to improve fuel economy. They are there to control exhaust emissions. Any device that improves fuel economy over a less costly device is merely attempting to restore the economy and driveability that is lost due to emission regulations. For example, the catalytic converter treats the exhaust gases outside of the engine and allows for engine adjustments to maximize fuel economy at a given regulatory level, but to call a catalytic converter a fuel economy device is misleading. If it were not for the need to control pollutants, a catalytic converter would not be installed on a vehicle.

GJB/rmn/th/025
3/15/77

SECTION 5

DRIVEABILITY

EPA has become more interested in the subject of vehicle driveability because the poor in-use emission performance of vehicles may be due, in large part, to maladjustments that were made in order to attempt to improve inadequate driveability performance.

The relationship between emission control, driveability, and fuel economy is expected to become an even more important concern as emission standards and fuel economy standards become more stringent.

It is expected that it will be a difficult technical job to provide vehicles with acceptable emissions, fuel economy, and driveability performance. Obtaining a satisfactory rating in more than one vehicle characteristic, for example emissions and driveability, as opposed to just emissions, is expected to require more effort and possibly require more sophisticated, complex, and costly technology.

Obtaining acceptable emissions, fuel economy, and driveability is expected to require a significant amount of effort beyond just that for obtaining acceptable emissions and fuel economy. Besides emissions/fuel economy considerations, emissions/driveability, and fuel economy/driveability relationships must be developed and considered. The level of effort required cannot be precisely determined, but it could be as large as that expended on emissions or fuel economy. Because standards exist for emissions and fuel economy, and not for driveability, it is possible that efforts concentrated on attaining acceptable driveability might be sacrificed in order to meet the requirements for emissions and fuel economy.

If the driveability of future vehicles is a problem, in-use driveability-induced maladjustments could negate the improvements in emissions and fuel economy that might be indicated by compliance testing. For that reason, this report includes a basic discussion of issues related to vehicle driveability.

Driveability is one of the performance characteristics of a vehicle. As used here, driveability is a subject separate from the quantification of vehicle performance that deals with acceleration performance and handling. In general, the evaluation of vehicle drivability involves an assessment of how well the vehicle responds to inputs from the driver. More specifically it concerns the degree to which the powertrain responds to the operator's instructions to deliver prompt, reliable, engine starts; smooth, responsive acceleration and cruise performance; and freedom from misfire, backfire, and other harsh operation. Figures Driveability-1* and -2* describe the common driveability problems.

The automotive industry has long been concerned with driveablity and has historically devoted considerable attention to optimizing the driveability of their products for all operating situations and ambient conditions.

The industry evaluates driveability by subjecting a vehicle to a series of tests that are designed to bring out any faults or problems. These tests include both cold start and hot start tests along with a wide assortment of acceleration and cruise conditions. These test procedures are designed by persons who are familiar with the common driveability weaknesses and who understand the underlying technical mechanisms behind them. As a result, the testing effectively surfaces any latent problems. Driveability problems can range in importance from items that are only mildly annoying such as a trace hesitation to such potentially hazardous conditions such as an engine stall when the vehicle is moving. To account for the varying significance of these conditions the manufacturers have devised complicated rating formulas that take into account both the nature and severity of the problems. The resultant rating is believed

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* Advanced Emission Control Program Status Report to the U.S. Environmental Protection Agency, Nissan Motor Co., Ltd., December 1976, pages A-2 and A-3.

Figure Driveability-1

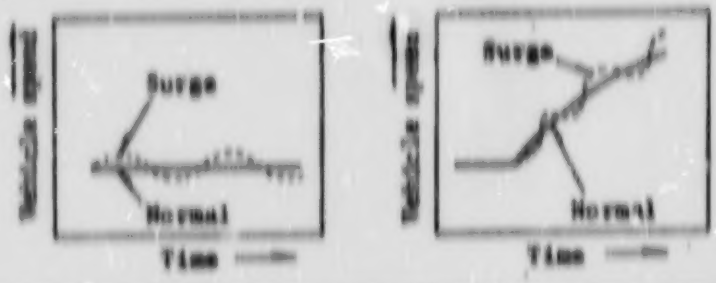
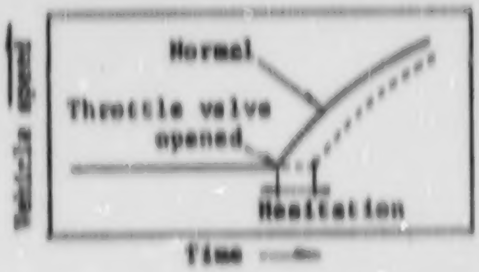
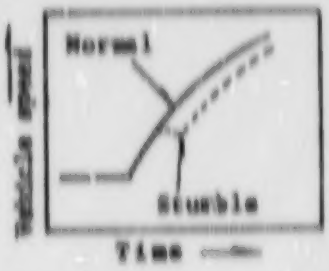
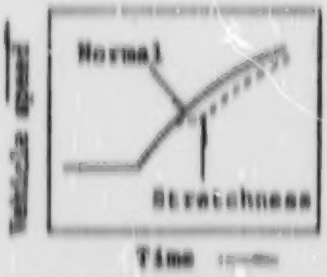
No.	Item	Definition
1	Surge	A continued condition of short, sharp fluctuations in power. 
2	Hesitation	A temporary lack of initial response in acceleration rate. 
3	Stumble	A short, sharp reduction in acceleration rate. 

Figure Driveability-2

No.	Item	Definition
4	Stretchness	A lack of anticipated response to throttle movement. 
5	Backfire	An audible explosion in the intake system.
6	Afterfire	An audible explosion in the exhaust system.
7	Idle Quality	A driver evaluation of the smoothness of the engine idle.
8	Startability	Start easiness.
9	Deceleration Performance	An ability of the engine to produce negative torque.
10	Run on	A condition where the engine continued to run after the ignition key off.
11	Stall	Any occation during the test on which the engine stops with the ignition switched on. Repeated stalls while starting the engine are not considered as stall.

to be an accurate measure of the average driver's overall impression of the vehicle driveability quality. Manufacturers generally have a minimum acceptable score for driveability which must be demonstrated by prototype vehicles before the manufacturers consider them to be marketed. Ford, for example, reduces their rating to a score that lies between zero and ten.

As indicated earlier, EPA's interest in driveability stems from the suspected role it plays in in-use vehicle emission performance. The Restorative Maintenance (RM) and Emission Factors (EF) test programs have shown that vehicle maladjustment is a major underlying cause of excessive in-use vehicle emissions. The nature and frequency of the maladjustments found in the RM and EF programs tend to fit a pattern which suggests that, rather than the random result of sloppy maintenance, these maladjustments were performed with an objective in mind. Two conceivable objectives are the improvement of fuel economy and the improvement of driveability. The net effect of these types of maladjustments has been a negative influence upon fuel economy. However, many of these changes can tend to have a positive effect upon driveability.

Some recent testing performed at the Sun Company Laboratories in Marcus Hook, Pennsylvania illustrates the magnitude of the effect that these maladjustments can have on a vehicle's driveability. The Coordinating Research Council (CRC) Cold Start Driveability Test was performed on a 1975 automobile in two states of tune. The first state corresponded to the factory correct condition with all engine adjustments conforming to the manufacturers specifications and with all emission control components operative. The second state was a maladjusted state, considered to be one that is within the capability of the service industry to perform.

The CRC Cold Start Driveability Test uses a demerit rating system which penalizes the car for objectionable performance. The higher the demerit rating, the worse the driveability. In the factory correct condition the vehicle scored 259 demerits. In the maladjusted state the vehicle scored only 72 demerits. Ratings are subjective but normally 300 demerits or more is considered very poor and 100 demerits or less is considered good. No emission testing was performed on this car but based on the types of maladjustments and their effect on emissions, it is reasonable to conclude that the vehicle would have exceeded the required emission levels in the maladjusted state.

The Coordinating Research Council performs periodic driveability testing on current model year vehicles. Figure Driveability-3* compares the driveability of representative samples of 1968, 1969, and 1973 cars. Because of the influence of fuel volatility, this figure compares the driveability for fuels with equivalent volatility ratings. It can be seen from this study that vehicle driveability experienced a significant decline between 1969 and 1973. Figure Driveability-4** compares the driveability of five matched pairs of 1973 and 1975 cars and shows that the average driveability tended to remain at about the same level between these years. No driveability test results have been released by CRC for the 1976 or 1977 model year vehicles but there have been indications that driveability has improved to some degree. If this is true, it may be due to the fact that the manufacturers have had several years at virtually constant emission levels and this may have allowed them to better optimize driveability. However, the future outlook is for significantly reduced emission levels. If these reductions are not accomplished in a skillfull manner that emphasizes good driveability, further deteriorations in vehicle driveability may occur. These in turn may result in increased incidences of maladjustment in in-use vehicles.

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* "1973 CRC Intermediate Temperature Driveability Program - Paso Robles", Prepared by the Coordinating Research Council, December 1975, page 37, (CRC Report No. 483).

** "Driveability Performance of 1975 Passenger Cars at Intermediate Ambient Temperatures - Paso Robles", Prepared by the Coordinating Research Council, December 1975, page 37, (CRC Report No. 486).

Figure Driveability-3

AVERAGE PERFORMANCE of 1973 and 1968-69 MODEL CARS at 40-50° F on SAME DRIVING SCHEDULE and DEMERIT SCALE

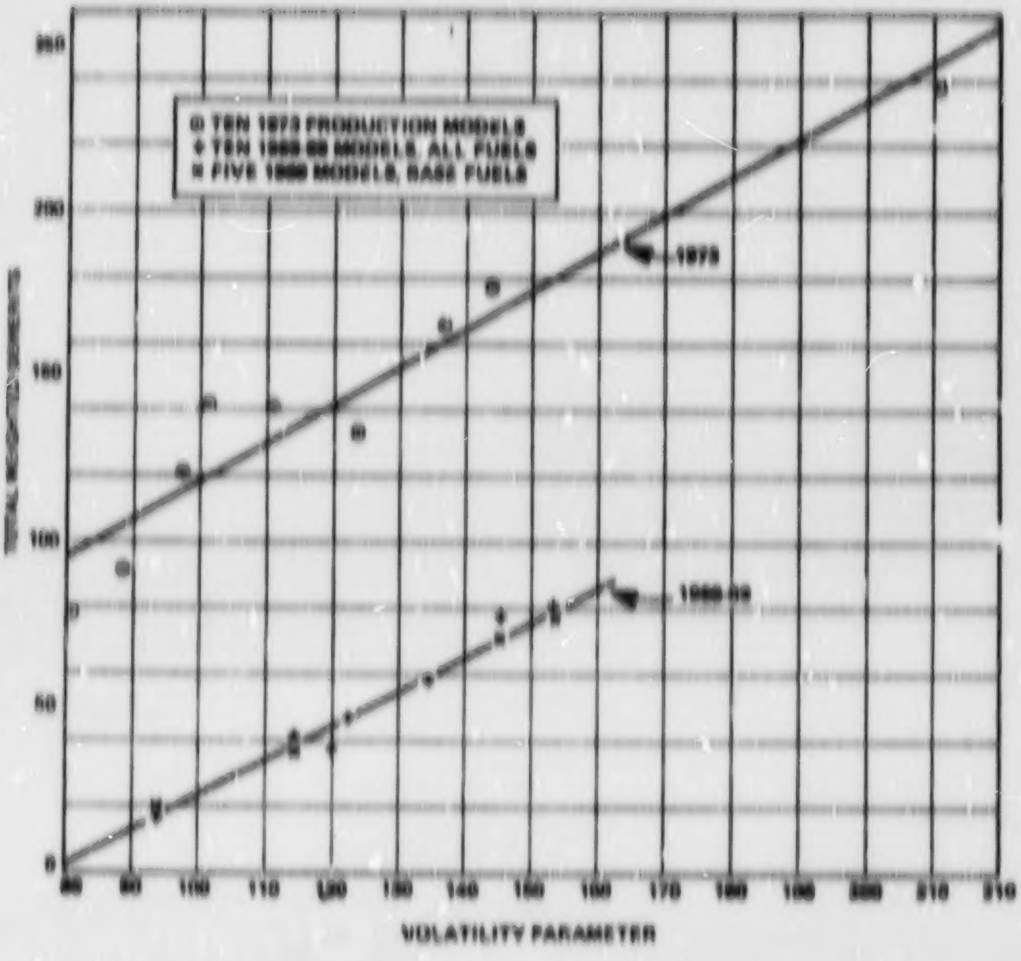
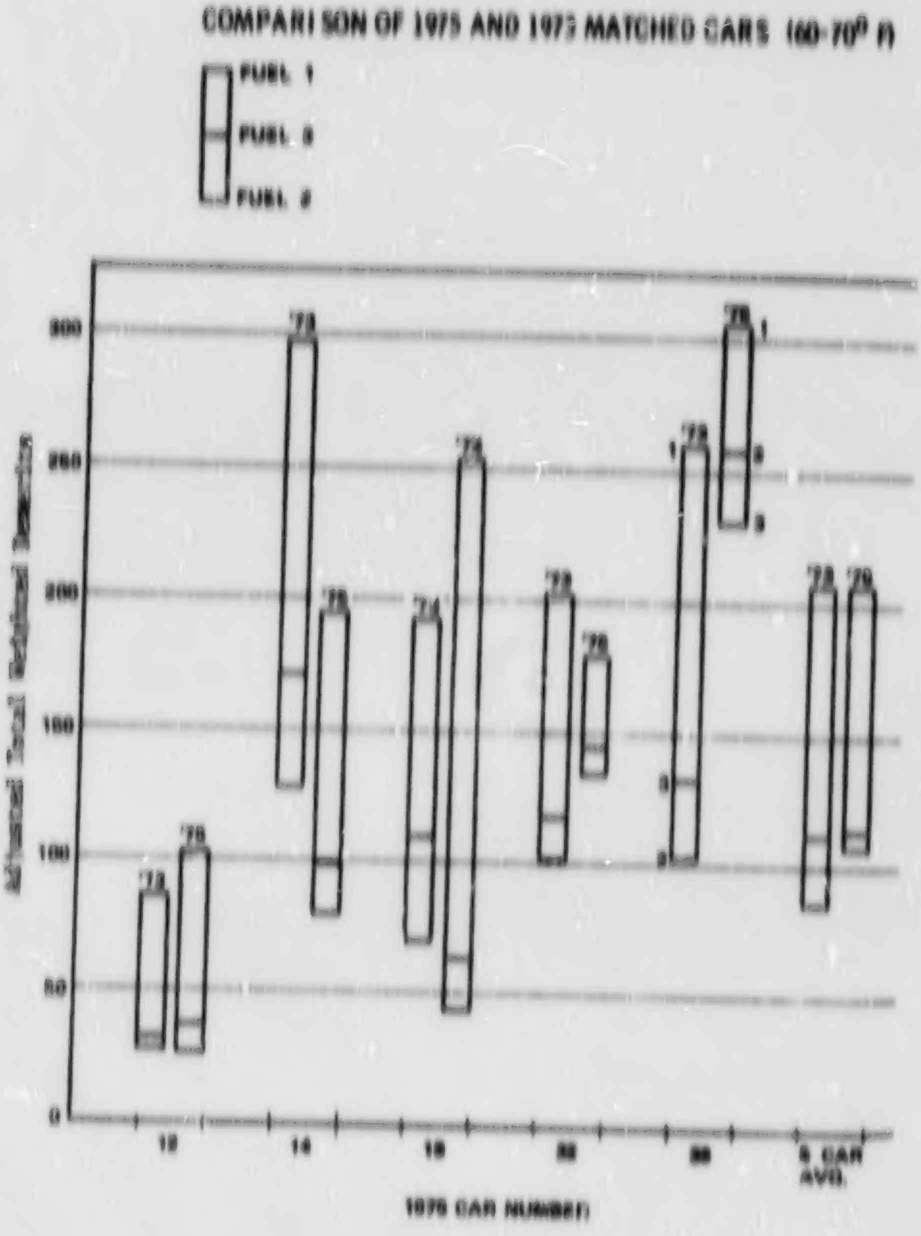


Figure Driveability-4



COMPARISON OF 1975 AND 1973 MATCHED CARS (60-70° F)

Fuel metering plays the largest single role in determining vehicle driveability and an analysis of its influence upon emission control can shed light on the typical conflicts and compromises that frequently occur. To perform smoothly and responsively, each engine cylinder must continuously receive a fuel-air mixture that is both readily combustible and correctly constituted for the power demands placed upon the engine at that moment. This requires that the fuel metering system adapt to rapidly changing power demands, mass flow rates and engine temperatures. Unfortunately, the conventional carburetion and manifold systems currently used on most engines have a difficult time metering and distributing the fuel with sufficient control accuracy. This results in wide swings in the air-fuel ratios being received by the individual cylinders. These swings can result in poor driveability. Spark ignition engines are particularly sensitive to lean excursions which can produce misfire, hesitation, stumble, and stalling. To counteract this, it was formerly a common practice for manufacturers to richen up the air-fuel ratio adjustments enough so that even during the leanest excursion encountered, the leanest cylinder in the engine would still be rich enough to avoid misfire, hesitation, etc. This practice of operating in a relatively rich regime, however, resulted in emission and fuel economy drawbacks. Most manufacturers responded to emission control requirements by leaning out the carburetor air-fuel ratios. For the most part this enleanment was not accompanied by any significant measures to improve the metering and distribution characteristics, which might have served to offset the negative impact on driveability.

Another important fuel metering characteristic that has had a negative influence on driveability is cold start enrichment. Conventional carburetion and induction systems do not vaporize fuel very effectively under cold start conditions. To make up for this, conventional carburetors employ chokes to add extra fuel. Because of the adverse effect of this extra fuel on emissions, the manufacturers have both leaned out the choke calibrations and reduced the time duration of the choke assisted period following cold start. This has been offset to some degree by quick heat intake manifolds and other aids to improve fuel vaporization but the impact upon driveability has until very recently been generally negative in spite of these measures.

Another item that has contributed significantly to degraded driveability is poorly tailored EGR. EGR works as an effective NOx suppressant by reducing peak combustion temperatures. NOx is produced by the engine at a rate that is dependent upon engine load. This means that to be most efficient in reducing NOx, the EGR flow rate should also be somewhat proportional to engine load. Fortunately, the engine's tolerance of EGR also tends to increase with load so that driveability is not necessarily affected by EGR when it is added at an efficient rate for NOx suppression. Many EGR systems, however, do not accurately tailor the EGR to be proportional to engine load. These systems often provide too much EGR at low engine loads and too little at high loads. This can cause excessive charge dilution and driveability problems. Some manufacturers are making progress in this area with, for example, the use of back-pressure modulated EGR systems which are more closely proportional.

Some other important contributors to poor driveability are retarded spark, positive crankcase ventilation, lowered compression ratio, and lower volatility fuel. The first three of these have been evidenced for several years and are fairly obvious in their cause and effect. The last, lower volatility fuel, is a recently reported condition which merits some discussion. As the demand for unleaded fuel rises, the petroleum industry is increasingly strained to meet the required volume while maintaining satisfactory octane ratings and volatility specifications. The octane problem is well known. The volatility problem has more recently come to EPA's attention. As was shown in Figure Driveability-1, volatility has a strong effect upon driveability. Spark ignition engines require a fuel which is well tailored to their starting and operating needs. This means that the fuel distillation curve should provide for sufficient vaporization of fuel at temperatures corresponding to cold start and normal operation without providing too much vaporization, which could lead to vapor lock and/or excessive evaporative emissions. This is accomplished by blending techniques which bring together many different hydrocarbon species. The distillation curve of the final blend satisfies the engine's varying needs reasonably well. The correct blend differs according to the ambient temperature, e.g., a winter blend needs a larger fraction of the high volatility components. There have been recent indications that the petroleum industry is having difficulty in supplying sufficient amounts of the high volatility constituents for unleaded fuels. This has reportedly caused some degradation in the cold starting performance of these fuels. This problem can be attacked either through blending or refining changes by the oil industry, or through engine/fuel metering modifications by the auto manufacturers.

An interesting related matter is the comparative volatility characteristics of the average gasolines in the field versus those of the official Certification fuel, Indolene Clear. Recent studies* have shown that typical field gasolines are less volatile than Indolene Clear and, hence, could be expected to result in generally poorer driveability performance. This is a matter of concern because the manufacturers develop and calibrate their vehicles for emissions to a large extent with the use of Indolene Clear in mind. Driveability problems, such as stalls, can increase emissions during the official EPA emission test. If vehicles are performing acceptably on the emission test, partially because of the superior fuel, they may have more driveability problems in the field with pump fuel.

The quantitative relationships between driveability and emission control were discussed in a Ford submission** to EPA. In this submission Ford reported that it employs "driveability trade-off factors" in determining their emission control capability. These factors were developed from vehicle test data for 1975 vehicle systems. The factors are as follows:

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* Bartlesville Energy Research Center (BERC) Survey,"BERC/PPS-76/1 Motor Gasoline, Summer 1975"by Ella Shelton published January 1976. Motor Vehicle Manufacturers Association (MVMA) National Fuel Survey, Fall Season, January 15, 1976.

**"Application for Suspension of 1977 Motor Vehicle Exhaust Emission Standards,"Submitted to EPA by Ford Motor Company, January 1975, Vol. 3, Appendix 3B.

+0.5 drive number = +0.1 HC, +2 CO, + 0.1 NOx
-0.5 drive number = -0.1 HC, -2 CO, -0.1 NOx

Ford's driveability rating is scored on a scale of 0 to 10. The above relationships between driveability and emissions are based upon a specific emission control technology, i.e., oxidation catalyst, AIR, EGR, etc. Different technologies will have different emissions/driveability relationships.

SECTION 6

UNREGULATED EMISSIONS

Introduction

As hydrocarbon, carbon monoxide, and nitrogen oxide emissions are controlled, various unregulated emissions may be altered. Introduction of a new emission control system can increase or decrease the level of a particular unregulated pollutant or, in extreme cases, result in formation of entirely new pollutants. It is important that these pollutants be characterized to be certain that control of regulated emissions creates no problems in other areas.

The unregulated pollutants discussed in this section are sulfuric acid, hydrogen cyanide, ammonia, ruthenium, polynuclear aromatic hydrocarbons, and Diesel particulate.

6.1. Sulfuric Acid

6.1.1. Introduction

The use of oxidation catalysts results in oxidation of both hydrocarbons and carbon monoxide. In addition, oxidation catalysts oxidize a portion of the sulfur dioxide in the exhaust to sulfuric acid. The sulfur dioxide in the exhaust is formed by combustion of trace quantities of organic sulfur compounds in gasoline to sulfur dioxide. Gasoline contains an average sulfur level of 0.03% which is very low compared to other fuels. As a result, sulfur dioxide emissions from gasoline-fueled vehicles are less than 1% of the total sulfur dioxide emissions. Most sulfur dioxide emissions come from stationary sources.

The sulfur dioxide in the atmosphere is photochemically oxidized to sulfuric acid. Even if the oxidation catalyst converted *all* of the sulfur dioxide to sulfuric acid, the resultant sulfuric acid contribution from these vehicles would be less than 1% of the total sulfuric acid in the atmosphere.

However, it is possible to have high localized levels of sulfuric acid along heavily traveled roads. EPA has determined that the condition of most concern is a heavily traveled freeway with maximum traffic flow. EPA developed a driving cycle called the Congested Freeway Driving Schedule (the CFDS) with an average speed of 35 mph to represent this condition. During the past year, various companies have obtained extensive emission data using this cycle. Laboratory studies have also been done to determine how different parameters (e.g. catalyst composition) affect sulfuric acid formation. Work has also been done to measure sulfuric acid levels along roadways and to determine vehicle sulfuric acid emissions at higher mileages.

6.1.2. Mechanisms and Laboratory Studies

Experiments were conducted by GM, Ford, and Chrysler using laboratory apparatus or, in some cases, engine dynamometers or vehicles, to determine the effect of various parameters on sulfuric acid formation. The laboratory work performed was less extensive than that conducted in previous years when little was known about the formation of sulfuric acid over automotive catalysts.

GM studies showed that rhodium containing catalysts produce less sulfuric acid than those containing only platinum or palladium. This confirms vehicle work done under an EPA contract with Exxon which showed that a rhodium containing catalyst had unusually low sulfuric acid emissions.

Ford studies on the effect of noble metal composition on sulfuric acid formation show that it is possible to produce a palladium catalyst that forms less sulfuric acid than either a platinum-palladium catalyst or a platinum-rhodium catalyst. Additional Ford work shows that a rhodium containing catalyst also has very low sulfuric acid emissions.

Ford conducted extensive engine dynamometer tests on 24 catalysts divided into four series (6 catalysts per series) to evaluate their sulfuric acid emissions. The catalysts were aged 100 hours for preconditioning prior to sulfuric acid testing. Catalyst light-off temperature and HC/CO conversion efficiency was measured at 800°F. Sulfuric acid measurements were made under conditions approximating 55 mph steady state operation of vehicle. Catalysts tested included Pt/Pd, Pt/Rh (with varying ratios of Pt/Rh), and platinum. The major finding of these tests is that rhodium containing catalysts emit less sulfuric acid than catalysts without rhodium. There is a marked change with catalysts containing more than 10% rhodium, which emit far less sulfuric acid (about 10% conversion) than catalysts with less than 10% rhodium (about 40% conversion). Ford indicated that there is a loss in HC control with the increased rhodium content. However, it appears that the change in HC emissions is less than that for sulfuric acid.

Ford also conducted some laboratory studies on catalysts that had been installed on vehicles and operated for 50,000 miles. Formation of sulfuric acid was compared between the 50,000 mile Engelhard II B catalysts and fresh catalysts. It was found that the aged catalysts had much lower sulfuric acid formation depending upon factors such as presence of reducing gases (certain HC compounds and CO), and space velocity. Even though the aged catalysts had high activity for propane and CO conversion, they had a two to six-fold decrease in sulfuric acid formation versus the fresh catalysts. These results are in accord with vehicle test data discussed later which show very low sulfuric acid emissions from catalyst vehicles with extended mileage.

GM conducted further experiments on the effect of temperature, space velocity, O_2 levels, and CO levels on sulfuric acid formation. It was found that low oxygen levels, higher CO levels, high catalyst temperature, and possibly low space velocity all lead to low sulfuric acid formation. These results are in complete agreement with previous tests run by GM, as well as past studies by Ford, Chrysler, other automobile manufacturers, and EPA contractors.

GM and Ford both reported results of laboratory studies on sulfuric acid storage. Storage of sulfuric acid occurs on fresh catalysts under most operating conditions, resulting in low sulfuric acid emission rates.

This effect is overcome on a vehicle, generally within the first 1000 miles. After that, high temperatures result in release of sulfuric acid (frequently as SO_2) with subsequent low temperature operation permitting storage once again. Since much of the stored sulfuric acid can be released as SO_2 at the higher temperatures, sulfuric acid emissions can be lower for systems which store significant quantities of sulfuric acid (e.g., pelleted catalyst systems). Again, this recent work agrees well with earlier work done by the automotive companies and EPA.

Ford reported some laboratory test results on both fresh and aged 3-way catalysts. The results on fresh catalysts show that all three 3-way catalysts tested (M-15202-3, M-253, and M-257) have comparatively low sulfuric acid formation (e.g., 40% formation) compared with a fresh Engelhard II B oxidation catalyst under the same conditions (e.g., 80% formation of sulfuric acid). These data indicate that some 3-way catalyst formulations have inherently lower sulfuric acid formation than conventional oxidation catalysts independent of other conditions (i.e., O_2 level). Dynamometer-aged 3-way catalysts were also evaluated in the laboratory reactor apparatus. Three-way catalyst samples aged for 470 hours showed about 10% sulfuric acid formation in a laboratory reactor compared with about 50% sulfuric acid formation for fresh catalyst samples.

Chrysler did some limited studies using a vehicle (Car 685) to investigate the effect of CO and O_2 levels on sulfuric acid formation. Chrysler modified the exhaust system of this car to allow injection of known quantities of CO and O_2. Sulfuric acid emissions were measured at 40 mph steady state conditions. The results of this work agree with earlier work showing that oxygen levels of 1% or less result in low sulfuric acid emissions (e.g., 1 mg/mi) while higher oxygen levels of 2% or more result in increased sulfuric acid emissions (e.g., 40 mg/mi or more).

Ford also did further work on how exhaust oxygen levels affect sulfuric acid emissions. A Pinto was equipped with a 3-way plus oxidation catalyst system. A managed air injection system (with a flow control valve in the secondary air flow upstream of the oxidation catalyst) was used to give variable amounts of oxygen (0.5%, 1%, 2%, and 5%). Complete test results are not available yet. Preliminary results suggest that lower oxygen levels result in lower sulfuric acid levels, but perhaps at the expense of some CO control.

Nissan has also done some engine dynamometer work on sulfuric acid using a 4 cylinder Datsun engine with either a pelleted or monolithic catalyst. This work shows a sharp increase in sulfuric acid emissions when the air-fuel ratio increases from 14.5 to 15.5 but only a moderate increase in sulfuric acid when the air-fuel ratio is increased further. This work also shows that monoliths and pellets emit the same quantity of sulfuric acid at temperatures over 600°C. Below this temperature, the monoliths tested by Nissan emitted more sulfuric acid presumably due to lower storage capacity. The Nissan work also shows lower sulfuric acid emissions from rhodium or barium (a stabiliser used in the substrate) containing catalysts. Additional work by Nissan shows sulfuric acid emissions to be greater for catalysts with more noble metal dispersed near the surface.

6.1.3. Sulfuric Acid Emission Data - Current Vehicles

GM tested seven of the 1975-76 vehicles used in their Sulfuric Acid Dispersion Experiment. These vehicles were tested on a driving schedule similar to the driving experienced around the GM Proving Ground track during the Sulfuric Acid Dispersion Experiment. This test cycle took two hours to complete with sulfuric acid measurements being taken every half hour (i.e., four measurements over two hours). The fuels used contained 0.032 wt % sulfur. The vehicles were tested at both the GM Proving Ground and Research Labs. The last sulfuric acid measurement for each vehicle is listed in the table below:

Table 6-1

Sulfuric Acid Emissions from
Dispersion Experiment Cars

Car	Lab*	Sulfuric Acid (mg/mi)
'75 302 Ford (Federal)	GM PG	31.8
	GM RL	41.1
'76 302 Ford (Federal)	GM PG	73.8
	GM RL	61.0
'75 Chevrolet (Federal)	GM PG	14.4
	GM RL	16.0
'75 Chevrolet (California)	GM PG	69.6
	GM RL	94.0
'75 Chevrolet (California)	GM PG	73.9
	GM RL	98.8
'75 318 Chrysler (California)	GM PG	84.6
	GM RL	78.2
'76 Pontiac	GM PG	32.7
	GM RL	55.1

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* Proving Ground = PG
Research Labs = RL

These tests showed an overall sulfuric acid emission rate of 51 mg/mi which compares with the 37 mg/mi emission rate calculated for the entire 352 car fleet used for the Sulfuric Acid Dispersion Experiment. There is reasonably good agreement between the two laboratories.

GM also measured sulfuric acid emissions from 12 other 1975-76 production vehicles, using the Congested Freeway Driving Schedule (CFDS). It is assumed that 0.032 wt % sulfur fuel was used. These test results are shown in the table that follows.

Table 6-2

Sulfuric Acid Emissions from GM Production Cars

Car	Emission Control System	Sulfuric Acid (mg/mi)
'75 Cadillac	California AIR	79
'75 Oldsmobile	California no AIR	17
'75 Nova	California AIR	136
'75 Vega	California AIR	18
'75 Vega	Federal pulsed AIR	1
'76 302 Ford	Federal AIR	58
'76 Cutlass	California no AIR*	17
'76 Cutlass	Federal no AIR	9
'76 Cutlass	California no AIR	2
'76 Cutlass	California AIR	44
'76 Nova	Federal no AIR	0.3
'76 Nova	Federal no AIR	0.3

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*3.6% exhaust O_2 for this car; O_2 not measured for other cars

These test results show that cars with air injection and presumably high exhaust oxygen levels have high sulfuric acid emissions while cars without air pumps and presumably low exhaust oxygen levels have much lower sulfuric acid emissions. Unfortunately, GM did not measure oxygen levels from these cars which would be useful in interpreting these results. Also, GM did not report the mileage of these vehicles.

Ford has measured sulfuric acid emissions from two 1976 Ford LTDs, a California version and a Federal version, both with the 400 CID engine. Ford not only obtained emission data on these cars but also investigated the effects of spark timing, EGR, oxygen concentration, and catalyst composition on sulfuric acid formation.

With the Federal car, Ford found high sulfuric acid emissions (about 50-60 mg/mi) with oxygen levels from 1% to 5%. Under 1% oxygen, the sulfuric acid emission levels decreased dramatically to under 20 mg/mi (as low as about 5 mg/mi in one test with about 0.3% oxygen). However, sulfuric acid emissions were under 10 mg/mi on this car over the CFDS with oxygen levels anywhere from 1.5% to 6.5%. It is unusual to see significantly higher sulfuric acid emissions at a steady state speed than over the CFDS. Other work conducted by EPA, GM, Exxon, Southwest Research Institute, and Chrysler did not indicate this phenomenon. Perhaps the higher sulfuric acid emissions are due to lower "spikes" of reducing gases such as HC and CO over a steady state mode versus a transient driving cycle. It could be that the particular Ford tested was more sensitive to such a phenomenon than other vehicles. It could also be that the immediate preconditioning before the CFDS resulted in purging of stored sulfuric acid with subsequent storage over the CFDS. It was found that changing the spark timing (from 6° to 16° BTDC) and plugging the EGR did not affect sulfuric acid over the CFDS.

Ford investigated the effect of using Pt/Pd, Pt/Rh, or Pd catalysts all with the same substrate on both the California and Federal cars. Tests of these catalysts on the Federal and California vehicle showed the following results.

Table 6-3

Sulfuric Acid Emissions of Different Catalysts

Vehicle	Catalyst	Driving Cycle	Sulfuric Acid (mg/mi)
Ford - Federal	Pt/Pd	45 mph	70
	Pt/Rh	45 mph	28
	Pd	45 mph	10
	Pt/Pd	CFDS	10
	Pt/Rh	CFDS	10
	Pd	CFDS	8
Ford - California	Pt/Pd	CFDS	28-40
	Pt/Rh	CFDS	25
	Pd	CFDS	42

These results show that Pt/Rh catalysts do no always give lower sulfuric acid emissions than other catalysts.

Ford also ran tests comparing different versions of the CFDS denoted as SET 7 and SET 7D. The SET 7 had more small speed fluctuations (called "noise") than the SET 7D. The SET 7 is extremely difficult if not impossible for the driver to follow all the time while the SET 7D has the "noise" modified by removing those parts difficult for the driver to follow. Furthermore, the present requirements outlining allowable driver tolerances for the FTP (± 2 mph within 1 sec) resulted in the earlier SET (the one with high "noise") having different drivers following the CFDS in different ways. That is, a driver could either follow or not follow the "noise" and still have a valid CFDS. Since the "noise" was difficult to follow, many drivers would not follow it. The modified CFDS (SET 7D) is easy enough for the average driver to follow the "noise" so that most cycles would be driven the same. Ford ran a total of about 6 SET 7 and SET 7Ds on a 1976 California Ford. Both cycles gave about 30 mg/mi sulfuric acid emissions with the SET 7D being about 18% lower than the SET 7. These results are in general agreement with those obtained by EPA even though the Ford results show greater differences. Extensive EPA tests (both in-house and at Southwest Research) on about 20 repetitions of the CFDS (both without any noise whatsoever, a precursor of SET 7, and SET 7D) show the SET 7D to have about 15% lower sulfuric acid emissions.

Chrysler ran sulfuric acid tests on two 1976 production vehicles. The first car (Car 176, a Dodge Coronet equipped with a 318 CID engine, a 90 cu in. catalyst, and an air pump) showed very high sulfuric acid emission (82 mg/mi) over the CFDS. The second vehicle (Car 155, a Dodge Dart equipped with a 225 CID engine, a 90 cu in. catalyst, and an air pump) showed much lower sulfuric acid emissions (9.4 mg/mi) over the CFDS.

Most of the test results on prototype cars are somewhat higher than those found in the EPA baseline study. This study involved sulfuric acid testing of 78 current and future prototype cars. These tests showed catalyst cars without air injection to emit about 10 mg/mi sulfuric acid while catalyst cars with air injection emitted about 20 mg/mi sulfuric acid.

6.1.4. Decrease in Sulfuric Acid Emissions with Extended Mileage

Very extensive sulfuric acid emission data have been taken on oxidation catalyst vehicles at low mileages. The bulk of these data were taken in 1975 and summarized in the EPA Status Report on Sulfate Emission Control Technology as well as the EPA Report on the Baseline Study. In the Baseline Study, about 60 vehicles were tested for sulfuric acid emissions. However, almost no sulfuric acid data have been taken on vehicles at extended mileage. EPA funded a major contract with Southwest Research Institute to measure sulfuric acid emissions on four catalyst vehicles as they accumulated 50,000 miles. Exxon Research and Engineering funded an in-house study to accumulate 50,000 miles on 20 cars and measure sulfuric acid emissions at various intervals. Both studies showed a significant decrease in sulfuric acid emissions occurring at roughly 20,000 miles. While sulfuric acid emissions can be high initially, most of the vehicles had emissions below 10 mg/mi after the drop occurred.

As a result of this work, EPA has asked the following companies to measure sulfuric acid emissions about every 5,000 miles on certain vehicles as they accumulate AMA type mileage.

Manufacturer	Number of Vehicles to be Tested
GM	12 cars
Ford	8
Chrysler	6
AMC	2
Toyota	2
Datsun	2
VW	2

These cars would probably come from existing fleets accumulating mileage (e.g., precertification fleet) to keep the cost of such a program at a lower level. The manufacturers have indicated their willingness to participate in this program and to have these tests completed by the end of 1977.

Aside from this program, both GM and Ford have reported current data on sulfuric acid emissions of cars at higher mileages.

GM is testing six vehicles (1975 Impalas) in a GM transportation pool as they accumulate mileage. Four of these cars were designed to meet the 1976 California standards while the other two cars are Federal cars. The cars currently have from 5,000 to 15,000 miles. The results to date are given in the table that follows for the CFDS and 60 mph cruise.

Table 6-4

GM Sulfuric Acid Tests of Transportation Pool Cars

Car	Mileage	Fuel Sulfur	Sulfuric Acid Emissions (mg/mi)	
			CFDS	60 mph
R5967 (Federal)	700	0.004%	0.3	7
	5000		0.4	9
R5949 (California)	600	0.004%	6	16
	10000		1	14
	15000		0.8	12
R5951 (California)	1800	0.004%	2	14
	5000		0.8	15
R5948 (Federal)	1700	0.036%	4	65
	5000		3	73
	11000		2	76
	15000		1	58
R5950 (California)	600	0.036%	108	136
	5000		55	111
	10000		15	132
R5952 (California)	800	0.036%	64	112
	10000		36	121
	15000		14	106

These results show a marked degradation in sulfuric acid emissions over the CFDS but very little degradation during 60 mph test conditions. Additional emission testing will be done as these cars accumulate mileage. GM did not report gaseous emissions (HC, CO, NOx) from these cars.

Ford ran a series of sulfuric acid emission tests on some of their 50,000 mile 1977 certification cars. The following test sequence was used with 0.03% sulfur fuel:

222 miles AMA preconditioning
LA-4 prep followed by cold soak
FTP
505 sec of LA-4
2 minutes idle
CFDS
10 minutes idle
CFDS
10 minutes idle
CFDS
10 minutes idle
CFDS
10 minutes idle
HFET

Each test was repeated on two additional days. Ford also tested three 1976 California Capri vehicles at 4,000 miles. The test results are given as follows. All of the vehicles had Pt/Pd catalysts and are 50,000 mile vehicles unless noted otherwise.

These vehicles frequently, but not always, show low sulfuric acid emissions at 50,000 miles. However, three of the cars had significantly higher sulfuric acid emissions (18-108 mg/mi) than the others. Ford points out that two of these cars also had low CO emissions, showing an inverse relationship between CO and sulfuric acid for this system. Ford is also measuring sulfuric acid on some of the 1978 certification cars.

Table 6-5

Ford Sulfuric Acid Test Results on 1976-77 Cars

Vehicle	Engine Disp.	Catalyst	Sulfuric Acid Emissions-CFDS (mgpm)	FTP Emissions (gm/mi) HC	CO	NOx
4A	2.3 litre	EI	0.51	0.20	3.86	1.29
5A	2.3 litre	MB	0.61	0.15	3.20	1.03
11A	2.3 litre	UOP	6.07	0.10	2.62	1.65
10A	2.3 litre	MB	0.61	0.11	4.47	1.75
10A	2.3 litre	MB	0.72	0.05	1.53	1.54
10A	2.3 litre	MB	0.47	0.05	1.72	1.50
21B	2.3 litre	EI	0.64	0.10	2.92	1.31
8A	2.8 litre	EI	1.67	0.12	2.16	0.96
14A	250 CID	UOP	1.98	0.16	5.25	0.93
16A	302 CID	UOP	45.65	0.10	0.66	1.13
17B	302 CID	UOP	107.80	0.07	0.12	0.94
14B	400 CID	EI	1.34	0.23	9.57	1.06
14B	400 CID	EI	1.79	0.15	7.88	1.02
21A	400 CID	EI	17.60	0.15	3.13	2.33
5C13*	2.3 litre	MB	21.57	0.08	0.12	1.00
5C15*	2.3 litre	MB	31.62	0.07	0.76	1.10
5C16*	2.3 litre	MB	9.39	0.07	0.44	0.86

* 1976 California 4K Vehicle

6.1.5. Sulfuric Acid Emissions from Future Prototypes

GM tested 12 future prototype vehicles for sulfuric acid emissions. These vehicles included lean burn and 3-way catalyst vehicles. The lean burn vehicles had higher sulfuric acid emission while the 3-way catalyst vehicles had low sulfuric acid emissions. The results of these tests for the CFDS are given below. GM did not supply gaseous emission results or any other details on the control systems other than what is listed in the table.

Ford measured sulfuric acid emissions from a variety of oxidation catalyst, 3-way and oxidation catalyst, and dual catalyst cars designed to meet low NOx standards. Even though two of the oxidation catalysts had 50,000 miles on them, the sulfuric acid emissions were still significantly high. The sulfuric acid emissions from the 3-way catalyst-oxidation catalyst prototypes were also high, because of SO_2 oxidation occurring over the oxidation catalyst with air injection before the oxidation catalyst. The conventional 3-way catalyst would, of course, be expected to have very low sulfuric acid emissions. Finally, Ford found high sulfuric acid emissions (69 mg/mi) from the Gould dual catalyst system. Independent EPA tests confirm that the Gould dual catalyst system does have high sulfuric acid emissions.

The results of the Ford tests are given in Table 6-7 for the CFDS.

Table 6-6

Sulfuric Acid Tests on
Prototype Vehicles

Car	Control System	Fuel Sulfur Level	Exhaust Oxygen Level	Sulfuric Acid (mg/mi)
'74 Chevelle	lean burn engine, production catalyst	0.06%	2.1%	59
'74 Chevelle	lean burn engine, production catalyst	0.031%	2.1%	42
'74 Chevrolet	closed loop fuel injection, 3-way catalyst	0.06%	0.7%	0.2
'74 Chevrolet	closed loop fuel injection, 3-way catalyst	0.06%	0.5%	0.1
'74 Chevrolet	closed loop carburetor, 3-way catalyst	0.031%	0.7%	0.2
'74 Oldsmobile	production catalyst, no AIR	0.031%	1.5%	44
'74 Oldsmobile	production catalyst, no AIR	0.031%	1.6%	76
'75 Chevelle	production catalyst, AIR	0.032%	1.5%	41
'75 Chevelle	production catalyst, warm-up catalyst, AIR	0.031%	1.5%	15
'75 non GM	stratified charge engine, fuel injection, monolith catalyst	0.012%	0.5%	6
'74 Chevelle	production catalyst, AIR switching	0.031%	1.6%	4

Table 6-7

Ford Sulfuric Acid Tests on Low NOx Prototypes

Vehicle	HC gm/mi	CO gm/mi	NOx gm/mi	H_2SO_4 mg/mi
8D1-302-5P (50K oxidation catalyst)	0.06	0.01	0.57	139.4
	–	–	–	103.2
	0.06	0.03	0.58	107.1
	0.07	0.00	0.61	110.9
	0.07	0.05	0.64	162.1
	–	–	–	106.9
	0.01	0.00	0.62	114.5
	0.05	0.01	0.62	115.4
	0.06	0.02	0.57	80.5
	–	–	–	86.8
	0.06	0.05	0.56	95.0
	0.06	0.03	0.56	87.8
	0.05	0.02	0.65	103.6
	–	–	–	95.6
	0.05	0.04	0.62	92.3
	0.05	0.00	0.62	104.6
8D1-302-5P (oxidation catalyst from 8D1-302-6P, 50K)	0.03	0.02	0.65	102.5
	0.03	0.02	0.60	117.9
	–	–	–	119.7
	0.04	0.01	0.65	106.8
8D1-302-6P (50K oxidation catalyst)	0.09	0.68	0.46	12.6
	–	–	–	19.9
	0.07	0.66	0.47	17.4
	0.12	0.68	0.47	19.4
	0.09	1.06	0.42	13.7
	–	–	–	12.8
	0.08	0.97	0.42	14.4
	0.08	0.83	0.43	15.3
8D1-302-1P (3-way and oxidation catalysts)	0.15	0.16	0.60	56.2
	–	–	–	51.2
	0.16	0.14	0.70	61.4
	0.15	0.13	0.67	62.3
	0.16	0.17	0.55	69.8
	–	–	–	53.6
	0.18	0.14	0.55	71.4
	0.18	0.18	0.56	61.2

Table 6-7 (cont.)

Vehicle	HC gm/mi	CO gm/mi	NOx gm/mi	H_2SO_4 mg/mi
8D1-302-7P	0.14	0.40	0.49	27.9
(3-way and	-	-	-	33.3
oxidation catlyst)	0.13	0.43	0.50	25.8
	0.14	0.29	0.49	34.5
	0.13	0.28	0.61	37.6
	-	-	-	43.0
	0.13	0.20	0.67	43.7
	0.14	0.26	0.64	40.1
Gould catalyst	0.33*	0.46*	0.25*	
(1975 400 CID LTD)	0.28	0.39	0.17	69.0

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* FTP data

Chrysler has run sulfuric acid emission tests on advanced prototype vehicles including the lean burn (with and without oxidation catalyst), start catalyst, and dual catalyst (Gould reduction catalyst followed by an oxidation catalyst) vehicles. The lean burn vehicles (cars 209 and 271) without catalyst showed very low sulfuric acid emissions while the lean burn vehicle (Car 4028) with oxidation catalyst showed higher sulfuric acid emission (41 mg/mi). Chrysler tested three start catalyst systems (Cars 454, 332, and 270) which were 1977 California prototypes. All three cars had 22 cu in. start catalysts and 90 cu in. main oxidation catalysts with air pumps. These three cars produced 53, 25, and 62 mg/mi sulfuric acid emissions over the CFDS which is in the same range as that expected from conventional oxidation catalysts without start catalysts.

Chrysler tested three dual catalyst type vehicles. The first of these, Car 178, had a Gould reduction catalyst followed by a 152 cu in. monolithic catalyst with an air pump. This car emitted a very low 5.4 mg/mi sulfuric acid over the CFDS which is similar to values Chrysler reported in 1975. The second car, Vehicle 232, has a monolithic Chrysler reduction catalyst followed by a 90 cu in. oxidation catalyst and air pump. This vehicle also produced very little sulfuric acid (13-25 mg/mi over the CFDS). The third vehicle (car #23) also has a monolithic Chrysler reduction catalyst followed by a 90 cu in. oxidation catalyst. This car has an air modulation system which injects about 7% oxygen upstream of the reduction catalyst for the first 90 seconds after a cold start. After this, sufficient air is injected into the oxidation catalyst to result in a 2% oxygen level (a diverter valve is used to achieve this). With the 2-3% oxygen level, 11.1 mg/mi of sulfuric acid is emitted over the CFDS. However, if the diverter valve is inoperative and all of the air is injected into the oxidation catalyst (7% oxygen), sulfuric acid emission levels of 46.3 mg/mi are observed over the CFDS.

The sulfuric acid emission results for the start catalyst and dual catalyst systems over the CFDS are given in the table that follows.

Table 6-8

Chrysler Sulfuric Acid Test Results

Vehicle	Sulfuric Acid (mg/mi)	Oxygen %	CO %
434 (start catalyst)	51.4	6.4	0.099
	59.4	4.9	0.466
	49.7	4.8	0.649
	13.6	3.2	0.850
	17.1	3.2	0.822
332 (start catalyst) Right Exhaust	14.5	3.0	0.220
	18.5	4.0	0.270
	12.9	4.0	0.304
	14.2	4.0	0.308
Left Exhaust	7.6	3.0	0.060
	14.8	4.0	0.043
	10.0	3.7	0.078
	13.2	4.0	0.068
Left Exhaust Dummy Main	2.9	4.0	0.090
Left Exhaust Dummy Start	6.8	3.3	0.358
	16.9	3.7	0.268
270 (start catalyst)	61.8	4.8	0.134
178 (dual catalyst)	5.4	2.2	3.257
232 (dual catalyst)	13.1	5.3	2.949
	15.6	6.1	2.767
	25.1	6.1	1.732
623 (dual catalyst)	11.1	3.3	2.66
	46.3	7.3	1.29

6.1.6. Sulfuric Acid Traps

GM is the only company reporting information on sulfuric acid traps. EPA has also done extensive work on sulfuric acid traps through a contract at Exxon Research and Engineering. The sulfuric acid trap is simply a chemical placed in a container (a muffler or catalyst-like container is satisfactory) on the vehicle after the oxidation catalyst. All of the exhaust passes through this container allowing the sulfuric acid to react with the sorbent.

The EPA work at Exxon showed several promising sorbents, the most promising of which was 85% CaO, 10% Al_2O_3, and 5% Na_2O. This sorbent can be fashioned into either pellets or rings. Tests on the sorbent show extremely high efficiency (about 90%) in trapping sulfuric acid even after extended mileage (25,000 miles). However, the sorbent swells causing an unacceptably high pressure drop causing the vehicle to lose power and increase its fuel consumption. EPA and Exxon spent a second year in a contract extension to try to remedy these problems and were unsuccessful. The second year Exxon program did identify a number of sorbents that could be considered promising. The overall conclusion of the EPA-Exxon work is that, if vehicle sulfuric acid reductions are needed, the sulfuric acid trap is a potentially promising candidate but will need a very large development effort. Even with a large development effort, it is not certain that a viable sulfuric acid trap would result.

In their work, GM screened many different sulfuric acid sorbents and found two promising candidates, CaO and a Na_2O-Al_2O_3 sorbent. The latter sorbent is especially attractive in that it is sufficiently selective that sulfuric acid alone with no SO_2 is trapped. A vehicle test on the CaO material showed 95% efficiency when fresh but only 70% efficiency (over the CFDS) or 40% efficiency (at 40 mph) after 32,000 km.

The Na_2O-Al_2O_3 trap has been tested only 1600 km and shows no loss in efficiency. Even though the GM program is less extensive than the EPA-Exxon program, the GM results seem to be in agreement with those of EPA-Exxon.

6.1.7. Sulfate Measurement Methods

Both GM and Ford reported work on measurement methods for sulfuric acid. This work involves both the collection methods used for automotive sampling and the analytical methods used on the collected samples.

GM has investigated CVS flow rate and concludes that either a 300 or 600 CFM flow rate is adequate for a large (18 inch diameter - 20 foot length) dilution tunnel. However, GM feels that a lower flow rate of 335 CFM will not work with a smaller dilution tunnel (8.4 inch diameter - 10 foot length) due to high sulfuric acid losses. The 335 CFM flow rate is used on almost all current CVS units. GM also stated that sample zone temperatures of over 200°F will result in lower sulfuric acid values (possibly by loss of sulfuric acid from the filter or incomplete condensation of sulfuric acid). GM also found that tunnel inlet temperatures of less than 200°F (caused by long connecting tubing between the vehicle and tunnel) cause low sulfuric acid readings. GM stated that smaller variations in paired samples were noted with critical flow venturi sampling versus CVS sampling. All of these items are being investigated by an EPA contract currently in progress at Southwest Research.

GM also stated that neither 5300 nor 25,000 CFM cooling fans result in vehicle temperatures during dynamometer operation that are typical of on-road operation. EPA generally uses a combination of several

5300 CFM fans to assure adequate cooling; EPA has also purchased a 25,000 CFM fan. EPA has just started a contract with Olson Laboratories to investigate the configuration of cooling fans that will result in vehicle cooling approximating that occurring during road operation.

Finally, GM notes that their work shows the perchlorate titration system to be equivalent to the barium chloranilate system for analysis of filter samples containing sulfuric acid. Ford has done similar work. EPA work also shows both systems are equivalent.

Ford has extensive work (both in-house and some EPA contract work) in progress investigating analytical methods for sulfuric acid and SO_2. Ford is currently working on an instrument for continuous SO_2 measurement of automotive exhaust. Furthermore, Ford is doing some work on analysis of sulfuric acid by mass spectrometry. In particular, electron impact mass spectral analysis offers the potential of distinguishing between sulfuric acid itself and salts of sulfuric acid (ammonium sulfate). Such instrumentation would be very useful in ambient air monitoring, where sulfuric acid particles could be distinguished from its salts. Such distinction is valuable since the two compounds probably have different health effects.

6.1.8. Correlation of Sulfuric Acid Tests among Different Laboratories

During the past year, several vehicles tested by GM and Ford have also been tested by EPA. Vehicles tested by the GM Proving Ground were also tested by EPA in the Sulfuric Acid Baseline Program. These tests showed generally good agreement between the laboratories.

Ford recently completed construction of dilution tunnels at their Scientific Research Laboratory and another Dearborn Laboratory. Ford tested a 1976 vehicle equipped with a 400 CID engine at both of their facilities and sent the car to EPA for correlation testing. The test results show reasonably good (but not complete) agreement among the three laboratories in the sulfuric acid emission values obtained.

As part of the sulfuric acid deterioration factor program to be conducted by the manufacturers and EPA during the coming year, sulfuric acid correlation testing will be needed among the different laboratories. A round robin car will be used for this purpose.

6.1.9. Roadside Sulfuric Acid Levels

Both the GM and Ford submissions discussed work on measuring roadside levels of sulfuric acid. In particular, GM completed a major experiment this past year titled the Sulfate Dispersion Experiment. This work involved running 352 cars, equipped with catalysts and air pumps (designed for the 1976 California standards), around a loop at the GM Proving Grounds. The cars were preconditioned with 0.032% sulfur fuel and operated at about 55 mph. The average sulfuric acid vehicle emission rate during these tests was about 0.037 mg/mi. Ambient air levels of sulfuric acid were monitored. Also, a tracer gas (SF_6) was emitted from eight pickup trucks participating in the experiment. Measuring the level of SF_6 and sulfuric acid under various meterological conditions allowed verification of an EPA predictive air quality model and also gave an independent measurement of roadside sulfuric acid levels.

It was found the normal levels of sulfuric acid in the air samples due to the vehicles were 3-5 $\mu g/m^3$. Under adverse meterology increments of 15 $\mu g/m^3$ were found. The increased level of sulfuric acid inside the vehicles was also measured and found to be about 4 $\mu g/m^3$. There was very good agreement between results obtained with the SF_6 tracer and the sulfuric acid measurements.

These results showed that the EPA Highway Model overpredicts sulfuric acid emissions at the pedestrian level downwind from the roadway. The overprediction occurs for stable meterological conditions and gets worse as the wind speed decreases (when roadside sulfuric acid levels would be highest). The EPA Highway Model is more or less satisfactory under unstable meterological conditions (when sulfuric acid levels along roadsides would be much lower). Apparently, "mechanical mixing" due to traffic flow is an important parameter and not accounted for in the EPA Highway Model. Various government agencies (EPA, DOT, and DHEW) as well as other automobiles companies helped participate in this work.

In addition to the massive GM experiment, Ford has been conducting monitoring experiments in the Allegheny Tunnel on the Pennsylvania Turnpike. Initially, Ford monitored rubber tire particulate there and then diesel and sulfuric acid particulate. The cars driving through the tunnel would be those designed for the Federal standards and therefore have lower sulfuric acid emission rates than the California cars used in the GM experiment. However, to date, no sulfuric acid increment has been noted from the introduction of catalyst cars.

6.1.10. Conclusions

Work during the past year confirmed earlier studies showing that exhaust oxygen levels are the most important single parameter affecting sulfuric acid emissions. Low exhaust oxygen levels (such as those found with 3-way catalyst cars) can result in sulfuric acid emission levels from catalyst cars of under 5 mg/mi which is equivalent to levels found with non-catalyst cars.

Sulfuric acid tests on current catalyst cars run this past year agree well with previous tests. Oxidation catalyst cars without air injection usually emit under 10 mg/mi of sulfuric acid. Current oxidation catalyst cars with air injection emit greater quantities of sulfuric acid, generally 20 mg/mi or higher. Tests of advanced oxidation catalyst vehicle prototypes (which generally have air injection) show similar sulfuric acid emission levels. Prototype 3-way catalyst cars show very low sulfuric acid emissions. However, 3-way catalyst cars with a downstream oxidation catalyst and air injection show sulfuric acid emission levels similar to conventional oxidation catalyst cars equipped with air injection.

One major area needing additional investigation is the effect of mileage on sulfuric acid emissions. Limited test results so far show high mileage oxidation catalyst vehicles have lower sulfuric acid emissions. Sulfuric acid emissions are reduced by a factor of two and, in some cases, even more. Some results have even approached the level of non-catalyst cars (1 mg/mi). Significant data are still needed to determine whether this reduction with extended mileage is such that sulfuric acid emissions are not a problem. The car companies are running tests on catalyst vehicles as they accumulate mileage to determine the extent of this reduction.

Finally, during the past year, GM completed a major test track experiment measuring roadside sulfuric acid levels. This work showed roadside sulfuric acid levels far below levels predicted by EPA air quality models. These lower levels, combined with a possible reduction in sulfuric acid emissions at higher mileages, may result sulfuric acid emissions being considered much less of an air quality problem than was previously the case.

6.2. Hydrogen Cyanide

6.2.1. Introduction and EPA Work

In 1974, it was reported by Bell Laboratories that automotive catalysts could, under very unusual conditions in a laboratory reactor, form hydrogen cyanide (HCN) from laboratory gases. EPA found in early 1976 that vehicles using a 3-way catalyst could produce HCN under rich malfunction modes. Since Volvo and Saab were certifying 3-way catalyst systems for use in California in 1977, EPA had to make a rapid determination on the levels of HCN that would be acceptable from a health standpoint. EPA was concerned primarily about the worst case situation, i.e. localized levels of HCN that could occur in indoor parking garages and along heavily traveled roadways. The highest HCN emissions were observed under rich malfunction modes when CO emissions were also highest (approaching levels found in some uncontrolled pre-1968 vehicles).

EPA considered two types of worst case situations in determining acceptable levels for HCN exposure in localized areas. The first was a closed environment situation (i.e. garage-type exposure) while the second was a highway-type exposure situation. In the closed environment situation, an upper bound of 5 ppm HCN could result from a maximum raw exhaust level of 10 ppm. The corresponding CO level under these conditions would be 6500 ppm. The adverse health effects of CO would overshadow possible adverse effects of HCN by more than two orders of magnitude. For the highway type exposure, a 150 mg/mi HCN emission rate would result in a 1.1 ppm HCN level with 17000 vehicles/hr. along a heavily traveled freeway, under the worst meteorological situation, with each car emitting the maximum amount of HCN. EPA-ORD states that 1 ppm HCN exposure would not have unacceptable health effects.

It was also thought that a primary factor affecting HCN formation was the rhodium content of the catalyst. The Engelhard catalysts planned for use by Volvo contained about 16% rhodium. Most 3-way catalysts contain rhodium, sometimes at lower levels (e.g. 7%). Many oxidation catalysts also contain small amounts of rhodium (i.e., 7% or less). Some 1975 Ford oxidation catalysts (those made by Matthey Bishop) and oxidation catalysts used by many of the foreign manufacturers contain rhodium.

EPA therefore required that all 1977 certification cars equipped with rhodium catalysts be tested by EPA-ORD for HCN emissions. All such cars tested to date have been below the HCN levels that had been established as safe with a large margin of safety on a preliminary basis by EPA.

Typical data found for a Volvo equipped with a 3-way catalyst by EPA-ORD are given below.

Table 6-9

EPA-ORD Test Results on Volvo
(Rich Malfunction)

Test	HC gm/mi	CO gm/mi	NOx gm/mi	HCN mg/mi	NH_3 mg/mi	H_2S mg/mi	COS mg/mi
Idle*	0.32	4.42	0.062	1.70	7.9	0.47	0.03
FTP	1.66	40.5	0.503	66.3	493	6.88	1.89
CFDS	1.13	28.2	0.314	110.6	627	10.1	2.11
HFET	0.88	22.4	0.383	78.8	735	7.59	1.72
30 mph	0.84	24.5	0.032	16.4	110	NA	1.32
40 mph	0.80	20.3	0.07	47.1	176	NA	0.71
50 mph	0.94	73.9	0.31	113.8	270	NA	1.16

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* g/minute

Another Volvo 3-way catalyst system (Car 7712) was tested by Exxon Research and Engineering under both normal and malfunction conditions. The rich malfunction mode was induced by disconnecting the oxygen sensor. Instead of the pyridine-pyrazolone wet chemistry method used for EPA for HCN analysis, Exxon used a selective ion electrode method. The results of the Exxon tests are given in the table that follows.

Table 6-10

Exxon Test Results on Volvo

Test	HC gm/mi	CO gm/mi	NOx gm/mi	HCN mg/mi	NH_3 mg/mi
		NORMAL OPERATING CONDITIONS			
Idle*	0	0	0.45	<0.4	5.0
FTP	0.21	2.70	0.32	<2.3	36.5
CFDS	0.08	0.55	0.11	<1.9	29.1
FET	0.05	0.31	0.08	<2.6	28.3
30	0.06	0.88	<0.02	<1.0	10.6
40	0.03	0.08	0.16	<0.6	10.6
50	0.06	0.45	0.08	<0.6	43.8
		RICH MALFUNCTION MODE			
Idle*	2.97	29.12	0.43	<0.4	9.4
FTP	1.08	24.97	0.74	22.5	327.8
CFDS	0.77	17.19	0.63	21.7	493.9
FET	0.68	14.36	1.14	19.3	425.4
30	0.76	19.27	0.16	29.0	187.1
40	0.90	15.97	0.30	62.0	481.4
50	0.85	24.55	0.68	146.5	749.0

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* g/minute

It can be seen from these data that HCN emissions are negligible under normal operating conditions. However, HCN emissions definitely increase under rich malfunction conditions to levels as high as 110 mg/mi.

Rhodium containing oxidation catalyst also has the potential of producing HCN under rich malfunction conditions. Since oxidation catalysts generally contain less rhodium than some 3-way catalysts, they would be expected to produce far less HCN. EPA-ORD tests on three VW 1977 certification cars show this to be true. The test results for one of these cars (an Audi 100) are given in the following table.

Table 6-11

EPA-ORD Test Results on VW Certification Cars

Vehicle	Test	HC gm/mi	CO gm/mi	NOx gm/mi	HCN mg/mi
Audi 100 (Car 5202, certification tune)	FTP	0.18	1.94	1.24	3.03
	CFDS	0.13	0.72	1.40	1.40
	FET	0.11	0.67	1.40	0.97
	IDLE (925 rpm)*	0.01	0.12	0.02	0
	IDLE (2000 rpm)*	0.12	0.03	0.05	0
Audi 100 (Car 5202, Rich malfunction, 1.6% CO)	FTP	0.36	9.92	1.15	5.65
	CFDS	0.22	3.83	1.05	3.37
	FET	0.12	1.44	1.16	1.09
	IDLE (925 rpm)*	0.11	4.28	0.02	1.08
	IDLE (2000 rpm)*	0.02	0.11	0.05	0.08

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* g/minute

Test results for two other VW certification cars (an Audi 80, Car 8389 and a VW Rabbit, Car 6846) were similar. The highest HCN emissions observed for these three cars was 7 mg/mi for the VW Rabbit over the FTP under the rich malfunction mode.

6.2.2. GM Work

In the 1975 Status Report, GM discussed tests they ran on non-catalyst cars and 1975 vehicles for HCN emissions. The non-catalyst cars emitted 11-14 mg/mi which should be considered the baseline with which all of the catalyst cars should be compared. The 1975 oxidation catalyst production cars emitted about 2 mg/mi.

In the 1975-76 work discussed in the most recent report, GM tested several additional cars for HCN emissions using a modified colorimetric method. The first cars tested were two 1975 GM production cars (Cars R5454 and R5452) designed to meet California standards with the standard Pt-Pd pelleted catalyst. The first car was tested with the air pump disconnected to enrichen the exhaust. CO emissions were lower (5.1 gm/mi) with the air pump disconnected than when it was connected (8.9 gm/mi). Under either condition, HCN emissions were very low at 2 mg/mi. The second car was run with both the standard and a specially designed rich operating carburetor. HCN emissions were very low under both conditions being 2 and 0 mg/mi respectively while CO was 3.1 and 96.1 gm/mi. While GM does not specify test conditions, it is assumed these cars were tested on the FTP.

GM also tested two experimental cars for HCN emissions (Cars CH42216 and ES66344). The first vehicle contained an experimental 3-way catalyst (HN-2217) and a closed-loop carburetor with an oxygen sensor. This car had FTP emissions of 3.1 HC, 85.5 CO, 0.7 NOx. However, HCN emissions were only 4 mg/mi. Presumably, this vehicle was operating under a malfunction condition giving the high CO emissions.

The second car was a Vega with electronic fuel injection, an oxygen sensor, and Degussa experimental 3-way catalyst (HN-3032). This vehicle was tested under both normal operating conditions and rich malfunction conditions. The rich malfunction was induced by enriching the car electronically in the open loop mode. The highest HCN value found in these tests was 18 mg/mi which is only slightly higher than HCN values found with non-catalyst cars during previous tests. The car was then retested in the closed-loop mode using an HN-3032 catalyst that had been aged 50,000 miles. HCN emissions were 9 mg/mi which is slightly higher than the fresh catalyst. The car was not tested in a malfunction mode with the aged catalyst.

The test results for this car are given below for the FTP.

Table 6-12

HCN Test Results of 3-Way Catalyst Vega

Test Condition	HC gm/mi	CO gm/mi	NOx gm/mi	HCN mg/mi	NH_3 mg/mi
Fresh catalyst					
closed loop	0.29	2.8	0.23	2	2
open loop -					
6% rich	0.30	3.4	0.86	2	3
12% rich	0.83	19.7	0.13	16	211
18% rich	1.75	60.0	0.11	11	259
50,000 mile catalyst					
closed loop	0.63	5.36	0.60	9	8

GM did not specify the rhodium content of the 3-way catalysts tested. However, HCN emissions from these catalysts are much lower than those found for the Volvo 3-way catalyst systems.

6.2.3. Ford Work

Ford has done more extensive work on HCN emissions than any other automobile company to date.

The initial Ford work involved lengthy validation of both the pyridine-pyrazolone and the ion selective electrode method for HCN. Both of these methods can be used to analyze HCN trapped in a potassium hydroxide solution contained in a bubbler. Ford bubbles a small sample from their dilution tunnel into the bubbler. The first test done by Ford showed the injection of 6.74 ppm HCN, approximately 90 mg/mi, resulted in 93.8% HCN recovery. The tests were repeated with lower levels of HCN injected. Quantities of HCN corresponding to 3.14 ppm or approximately 45 mg/mi resulted in poor recovery, the reasons for which are unknown at the present time. Ford then added known quantities of HCN to the dilution tunnel stream when a vehicle was being tested at a 45 mph cruise condition. These tests showed an HCN recovery rate of only 50% indicating an interference problem with both methods. Ford work identified the problem to probably be a low concentration of potassium hydroxide in the bubblers (caused by reaction of acidic exhaust components) which allowed HCN to escape. Modifying the method by using more hydroxide resulted in a recovery of 94% of the HCN. Ford work shows the limit of detection of both methods is about 0.06 mg/mi of HCN. While more work is needed to refine the method, the method as it stands now can be used for reasonable approximation of automotive HCN emissions.

Ford vehicle tests were conducted on a Granada equipped with a 302 CID engine and a 3-way catalyst followed by an oxidation catalyst (Vehicle 9P), a Pinto equipped with a 2.3 litre engine with a similar system, and a 1978 prototype Pinto with a 2-way catalyst.

Tests on the Granada were conducted with the air injection functioning normally and with the air injection after the 3-way catalyst disconnected simulating a rich malfunction condition. This car was tested over the CFDS, idle, and 45 mph steady state conditions. With the air pump disconnected, HCN emissions were 12.3 mg/mi compared to about 0.15 mg/mi with the air pump functioning. CO emissions over the CFDS were about 16 gm/mi with the air pump disconnectud and only 2 gm/mi with the air pump functioning.

The Pinto (Vehicle T791) with the 3-way plus oxidation catalyst system was tested under the same conditions as Vehicle 9P. The HCN emissions were under 5 mg/mi for all tests. CO emissions were extremely low both with the air pump disconnected (under 0.1 gm/mi) and with it functioning correctly (also under 0.1 gm/mi). It is possible that the low CO on Vehicles 9P and T791 are partly responsible for the low HCN formation.

The 1978 3-way catalyst prototype (Vehicle 61828) was tested with a line to the carburetor being plugged to deactivate the oxygen sensor. This resulted in a 12:1 air-fuel ratio. The vehicle was also tested in a 13:1 air-fuel ratio configuration. The car was tested under idle (slow and fast), 50 mph, the CFDS, a hot start FTP, and the FET. HCN emissions were in all cases under 3 mg/mi. However, CO emissions were considerably higher than usual (96, 113, and 88 gm/mi over the CFDS, hot start FTP, and FET) giving ample opportunity for HCN formation.

Finally, Ford has done some laboratory studies with catalyst samples in their pulse flame reactor and also with simulated exhaust gas samples blended from gas cylinders.

The simulated exhaust gas experiments showed that higher NO and CO concentrations caused higher HCN formation as expected. Maximum HCN from a Pt-Pd PTX catalyst and a pure platinum catalyst is formed at 550°C. The temperature for maximum HCN formation is slightly lower for a rhodium containing catalyst. Space velocity (from 20,000 to 200,000 hr^{-1}) did not influence HCN formation at 550°C. It should be noted that the simulated exhaust contained NO, CO, and hydrogen but no water vapor (a component normally found in vehicle exhaust).

However, the pulse flame reactor tests show that roughly the same amount of HCN is formed from 550° to 800°C for all of the catalysts tested (except one containing iridium). Additional tests showed that lower space velocities decrease HCN formation. The pulse flame apparatus results may be different from the laboratory test apparatus results because the gas used in the former experiments contained water vapor.

6.2.4. Chrysler Work

The initial Chrysler work on HCN consisted of running engine dynamometer tests with a variety of catalysts. Catalysts tested included an Engelhard Pt/Rh and three Chrysler catalysts (Pt, ruthenium-perovskite, and Pt/Rh). These tests were run with 1.5% to 5% CO (mostly 5%). Even though the CO levels were high, less than 1 ppm of HCN was formed. Chrysler even ran an engine dynamometer test with the catalyst at 1300°F where they thought HCN formation would be a maximum. Again, almost no HCN was formed.

Chrysler then decided to run some basic laboratory tests with simulated exhaust gases. Using a gas containing 3% CO, 1% hydrogen, and 0.2% NO in nitrogen, the following results were obtained with different catalysts.

Table 6-13

Chrysler HCN Laboratory Studies

Catalyst	HCN (ppm)
platinum-rhodium	72
platinum	0.9
ruthenium-perovskite	<0.5
rhodium	160

Further tests with the platinum-rhodium catalyst shows that doubling the CO input also doubles the HCN emissions. Doubling the NO input also increases the HCN emissions but by less than a factor of two.

Chrysler did some further tube furnace laboratory studies involving the platinum-rhodium catalyst in one furnace and a platinum catalyst in a second furnace (in series). Such an arrangement approximates a dual catalyst system (a reduction catalyst followed by an oxidation catalyst).

On a dual catalyst system, an air pump provides air injection after the reduction catalyst but before the oxidation catalyst. A vehicle air pump failure can be easily simulated in the tube furnace by not adding air between the two furnaces. Chrysler did this and varied the temperature of the oxidizing catalyst. The following results were obtained using two different feedgases.

Table 6-14

Chrysler HCN Laboratory Studies

Feedgas A[1]		Feedgas B[2]	
Temperature	HCN (ppm)	Temperature	HCN (ppm)
600°F	67	750°F	3
800	65	900	3
1000	67	1050	9
1300	114	1200	49
		1350	92
(oxidizing catalyst removed)	65	1500	88

[1] Feedgas A: 1.9% CO
0.8% hydrogen
0.19% NO
rest nitrogen

[2] Feedgas B: 0.7% ammonia
1.9% CO
0.8% hydrogen
rest nitrogen

These results show the greatest HCN emissions at about 1300° F.

Finally, Chrysler reports some work done on analytical methods. Chrysler uses the Liebig titration, the pyridine-pyrazolone method, and the selective ion electrode method. Chrysler states that heavy metals (nickel, copper, iron, and zinc) and the sulfide anion interfere with the selective ion electrode. However, Chrysler finds no evidence of any of these interfering species in the liquid impinger sample they collected.

6.2.5. Conclusions

Early studies by EPA showed HCN emissions from vehicles with 3-way catalysts operated under malfunction conditions. These emissions were always under 150 mg/mi for any driving mode and under 5 ppm for idle. Almost no HCN emissions were found from vehicles with 3-way catalysts under normal operating conditions. EPA has concluded that these levels of HCN do not represent a health concern.

The manufacturers have done extensive work developing analytical methods to measure HCN emissions. Also, considerable work was done measuring HCN on a number of non-catalyst and catalyst cars. Non-catalyst cars have been found to emit from 11-14 mg/mi of HCN. Oxidation catalyst cars emit far less HCN than non-catalyst cars even under malfunction conditions.

Therefore, currently available data indicate HCN emissions from catalyst cars is not a problem. However, HCN measurements should, of course, be done on future emission control systems as they are developed.

6.3 Ruthenium Emissions

6.3.1. Introduction

Ruthenium is being considered by several companies for use in catalysts. Chrysler has considered it for reduction catalysts, 3-way catalysts, and start catalysts. Ford has conducted extensive work with ruthenium for use in reduction catalysts. In addition, both Exxon and Gulf had done work in the past on ruthenium containing reduction catalysts but are not now conducting any further work. The basic reason ruthenium is being considered is its low cost and attractiveness for nitrogen oxide control. Ford has considered use of ruthenium in the past for NOx reduction catalysts and is currently considering ruthenium as a possible component of 3-way catalysts.

The higher oxides of ruthenium (RuO_4) are volatile and easily formed under oxidizing conditions. Various companies in previous years (Ford and Exxon) have tried to stabilize ruthenium so that it is not lost from NOx reduction catalysts. These attempts were unsuccessful due to high loss of catalytic activity in the process or the loss of ruthenium. Recently, DuPont has worked on stabilizing ruthenium in a rare earth oxide perovskite structure. This work is still in progress. Since ruthenium oxides are very toxic, it seems that use of ruthenium catalysts depends on no significant emission of their oxides. EPA is not currently in a position to quantify what, if any, levels of ruthenium emissions would be considered significant. EPA health effects studies are investigating the toxicity of ruthenium and ruthenium oxides.

6.3.2. Chrysler

Chrysler is the only company to have reported studies on ruthenium emissions. Chrysler ran dynamometer and vehicle tests. Chrysler also sent the vehicle they tested to Exxon for independent tests.

The dynamometer tests showed from 14 to 36 mg/km of ruthenium being emitted. At this rate, all of the ruthenium would be lost in 32,000 miles.

Chrysler has also conducted ruthenium tests on Research Car 232. Car 232 contains a small (50 cu in.) ruthenium perovskite monolith catalyst close to the exhaust manifold. This catalyst can function as a reduction catalyst. A conventional Pt oxidation catalyst follows the reduction catalyst. Particulate samples were collected from the dilution tunnel using a Fluoropore filter which was analyzed for ruthenium by neutron activation. This car was run on AMA durability for 25,000 miles. The Chrysler tests indicated significant ruthenium loss. After 25,000 miles, the car was sent to Exxon for particulate tests. These tests showed again that ruthenium was being emitted at a substantial rate (about 150 mg/mi). The Exxon results were about three times higher than the Chrysler results. The Chrysler results indicated that all of the ruthenium on the catalyst would be lost in about 30,000 miles (if the emission rate were constant).

6.3.3. Conclusions

Tests by Chrysler show that ruthenium is in fact lost from ruthenium-containing catalysts. While ruthenium is not being used in any production catalysts currently, it is being considered for future catalysts. It is important that ruthenium losses be measured from prototype catalysts so that the health impact of these emissions can be determined.

6.4. Ammonia

6.4.1. Introduction and EPA Work

Ammonia emissions have been known to occur for some time now with dual catalyst systems under rich operating conditions. With a dual catalyst system, ammonia formed over the reduction catalyst is frequently reoxidized to NO over the oxidation catalyst. Ammonia formation in a dual catalyst system thus generally results in loss of NO control. It is possible to have incomplete oxidation of the ammonia over the oxidation catalyst which could result in significant ammonia emissions. Also, an oxidation catalyst system malfunction (e.g., air pump failure) can result in significant ammonia emissions.

In addition to possible ammonia formation with dual catalysts, ammonia can be formed with 3-way catalyst systems. Early EPA data show that the Volvo 3-way catalyst can have significant ammonia emissions under rich malfunction conditions. Data obtained by EPA-ORD and Exxon on ammonia emissions was given in detail in some of the tables in the HCN section. Essentially, these data showed 20-30 mg/mi ammonia under cyclic operation conditions with the vehicle correctly tuned and as high as 300-500 mg/mi under rich operating conditions.

Ford points out in their status report that ammonia will be emitted from their 3-way catalyst systems. Ford has also asked EPA from time to time on what level of ammonia emissions would be acceptable from a health standpoint. EPA is currently investigating possible health effects from automotive ammonia emissions including both entire air quality regions and localized situations (e.g., indoor parking garages and heavily traveled freeways). Currently, there is inadequate information to permit determination of the level of automotive ammonia emissions that would be acceptable.

6.4.2. Ford Work

Ford routinely measures ammonia emissions in all of their 3-way catalyst screening work. A parametric study performed by Ford on catalysts identical in all aspects but Pt/Rh ratio shows a linear decrease of net NOx conversion (which is inversely related to ammonia formation) with increasing Pt/Rh ratio.

Laboratory studies of various catalysts show increasing ammonia formation as the A/F ratio becomes "richer" in the laboratory pulsator apparatus. For example, catalyst H268A shows an increase in ammonia formation from 0% of total NOx to 20% as the A/F ratio changes from 14.38 to 14.08. Catalyst H268B shows a change in ammonia formation of only 0% to 2% under these conditions. Catalyst H275D2 produces from about 0% to 40% ammonia as the A/F ratio is changed from 14.48 to 14.08. These tests were generally run at 550°C.

Ford has also done some ammonia measurements of 3-way catalysts being durability tested. Testing was done with isooctane containing 0.007 gm/gal lead, 0.0008 gm/gal phosphorus, and 0.02% sulfur. As the catalyst ages, the A/F ratio units for optimum NO, CO, and HC conversion generally shifts about 0.1 A/F units to the rich side. Ammonia formation was noted to decrease significantly in some of the catalysts (H-270 and H-273), thereby aiding net NOx conversion.

Ford also reported some engine dynamometer work on ammonia formation with catalysts containing differing amounts of rhodium. The results were those obtained in the laboratory apparatus mentioned earlier. These tests showed the ammonia formation was found to be inversely proportional to the rhodium content of the catalyst. Perhaps sulfur poisoning of the aged catalyst results in different ammonia formation characteristics than a fresh catalyst.

Finally, Ford reported ammonia formation characteristics of an experimental 3-way catalyst containing 3% TiO_2 (titanium oxide). The TiO_2 apparently affects oxygen storage capacity and the rates of oxygen transfer. The ammonia formation from this catalyst was very high, 26% at a point 2% rich of stoichiometric.

6.4.3. GM Work

Last year GM reported that ammonia emissions from four catalyst prototype vehicles are 1-3 mg/mi over the FTP.

Table 6-15

GM Ammonia Data

Car	Catalyst	Ammonia mg/mi
0-39680	HN 2236	3
0-38608	HN 2236, AIR	2
R564346	HN 2221 and 2364 (dual catalyst, reduction and oxidation)	1
C4361	HN 2217 and 3059 3-way + oxid. catalyst, closed loop fuel injection	2

GM work on 1975 production cars without air injection under rich malfunction conditions show ammonia emissions of 43-165 mg/mi. In this year's status report, GM reports ammonia emissions on a 1975 Vega with a 3-way catalyst. Since this car was also tested for HCN emissions, the ammonia test results were given previously in the HCN section. This car showed 2-8 mg/mi of ammonia under normal operating conditions, 3 mg/mi when operating 6% rich, and 211-259 mg/mi when operating 12-18% rich.

GM also tested four 1975 catalyst cars and one 1974 non-catalyst car for organic amines over the FTP. Amine compounds are very similar to ammonia. No amine emissions were found using the wet chemistry iodiometric analysis method which has a limit of detection of 2 mg/mi.

6.4.4. Conclusions

Ammonia emissions may be significant from vehicles with 3-way catalysts but only under malfunction conditions. Ammonia emissions should be measured from vehicles with 3-way catalysts as they are being developed.

Ammonia emissions from vehicles equipped with oxidation catalysts do not appear to be significant.

6.5. Polynuclear Aromatic Compounds (PNA)

6.5.1. Introduction

Polynuclear aromatic compounds (PNAs) are of interest due to their carcinogenicity. The PNAs are a group of multi-ring aromatic hydrocarbon compounds with very low volatility and high molecular weight. About 90% of total PNAs in the atmosphere come from stationary sources (in particular from coal burning). Only about 10% of the total PNAs come from mobile sources. Even though little PNA work has been done on Diesels, it is estimated that about half of this 10% comes from Diesels. The other half of the 10% comes from other motor vehicles.

Sometimes benzo(a)pyrene (BaP) is measured by itself instead of measuring total PNAs (which consist of about 20 compounds). The amount of BaP found can generally be correlated to total PNAs. BaP is relatively easy to measure and is more carcinogenic than most other PNAs.

PNA compounds in automotive exhaust have been studied for some time. Early contract work through CRC-APRAC from 1968-72 thoroughly characterized PNAs. This work was done at Exxon and involved testing several cars. It was found that post-1968 cars had about half the PNA emissions of pre-1968 cars. The control of HC and CO also resulted in decreases of PNA. Exxon did some work on prototypes equipped with advanced catalysts and thermal reactors. Both systems were found to greatly reduce PNAs (generally by 95% or more compared to uncontrolled vehicles. Subsequent work by UOP showed that catalysts preferentially oxidize PNA compounds resulting in very low PNA emissions from vehicles with catalysts.

Very little work has been done on measuring PNAs from light duty Diesels. However, work at Southwest shows heavy duty Diesels emit much greater quantities of PNAs than do gasoline engines. It is important that PNA work be done on light duty Diesels.

6.5.2. VW Work

The only PNA data reported in the submissions came from VW.

Volkswagen (VW) presented an interesting summary and discussion of their testing concerning the levels of PNA from different types of emission control technologies, alternative engines, and alternative fuels. VW did not provide complete details concerning the test procedures utilized in VW's testing for PNAs. Also missing from the VW discussion was any mention of PNA emissions from Diesel engines.

VW reported that their studies showed extremely low levels of PNA concentrations in automobile exhaust emissions. These levels are reported to be approximately 0.001 gm/km (0.0016 gm/mi) on the European Emission Test Procedure. This level is higher than found by other investigations.

In addition to utilizing the European Test Procedure, the data were collected under the following conditions:

(1) Europe Fuel ERF-01 was used in all procedures. This type of fuel has a composition of 55% paraffins, 8% olefins, and 37% aromatics. Its lead content is 0.71 gm/litre (2.68 gm/gal). Lead free fuel (VK 91) was used with noble metal catalyst equipped engines. The lead free fuel contains 1% more aromatics.

(2) The motor oil was a standard brand heavy duty oil. The oil was changed before every PNA test to avoid PNA enrichment of engine oil.

(3) The test vehicles had accumulated between 2,000 and 15,000 miles of city driving at the start of the test.

Volkswagen presented the data in Figure VE-1 which illustrate the distribution by percent of PNAs in automobile exhaust emissions produced by a variety of engine design concepts. The column labeled "Carcinogenic properties" is VW's estimate of the relative severity or danger of producing cancerous effects in humans. This opinion does not reflect EPA's position indicating which PNA are more carcinogenic than others. It should also be noted that the PNA listed in Figure VE-1 are less stable as they proceded down the list and hence easier to break down with exhaust aftertreatment.

Volkswagen drew the following conclusions concerning PNA from vehicles equipped with gasoline fueled engines:

(1) There is a certain and insignificantly varying pattern of distribution of the measured ten individual PNA components from fluoranthene through coronene. The lower four-ring PNAs represent approximately 80% of this pattern. VW mentioned that among the ten measured PNA components there are three each which combine two or three individual PNA components. There is one triplet each in the chrysene and in the benzo-fluoranthenes, and one twin in the indenopyrene.

(2) The present production vehicles produce the following scatter on European Test Procedure - PNA total emissions of between 2000 ugm/test and 10,000 ugm/test, and between 30 ugm/test and 215 ugm/test in the benzo(a)pyrene emissions.

(3) The following percent reduction of PNA emissions are obtained with other concepts when compared to gasoline powered vehicles.

production vehicles = 100%
catalytic design concepts = 5%
thermal reactor concepts = 15%
methanol vehicles = 10%

Figure VB-1

PNA	Cancerogenic properties + slight ++medium +++strong	Vehicle Concepts			
		Production Vehicles	Catalytic Concepts	Thermal Reactor Concepts	Methanol Vehicles
		% of TOTAL PNA			
FLUORANTHENE	0	24	22	25	37
PYRENE	0	36	26	32	42
CHRYSENE + M 226 + BENZO(A)ANTHRACENE	+	20	15	13	8
BENZOFLUORANTHENE	++	3	5	5	3
BENZO(E)PYRENE	+	2,5	4	4	2
BENZO(A)PYRENE	+++	2,5	2,5	2,5	1,5
PERYLENE	0	0,5	0,5	0,5	0,3
INDENOPYRENE + DIBENZ(AH)ANTHRACENE	+ +++	2	4	2	1,5
BENZO(G,H,I)PERYLENE	0	7	11	9	3
CORONENE	0	4,5	9	7	2

% DISTRIBUTION OF TOTAL PNA	100 %	5 %	15 %	10 %
TOTALS IN VARIOUS PRODUCTION VEHICLES IN µg / Test	2000 to 10 000			

PERCENT SHARE OF CANCEROGENIC PNA'S	approx 20 to 30%

PNA PERCENT DISTRIBUTION
IN EXHAUST EMISSIONS
(BASIS EUROPE TEST)

6-47

(4) The distribution pattern of vehicle concepts other than production vehicles show limited but characteristically shifted PNA patterns. The four-ring PNAs are lower in catalytic concepts than in the thermal reactor concepts while the six and seven-ring benzo(ghi)perylene and coronene components show a distinct increase in the catalytic concepts. This indicates that these after-burner concepts reduce the latter components less when compared with the lower PNAs.

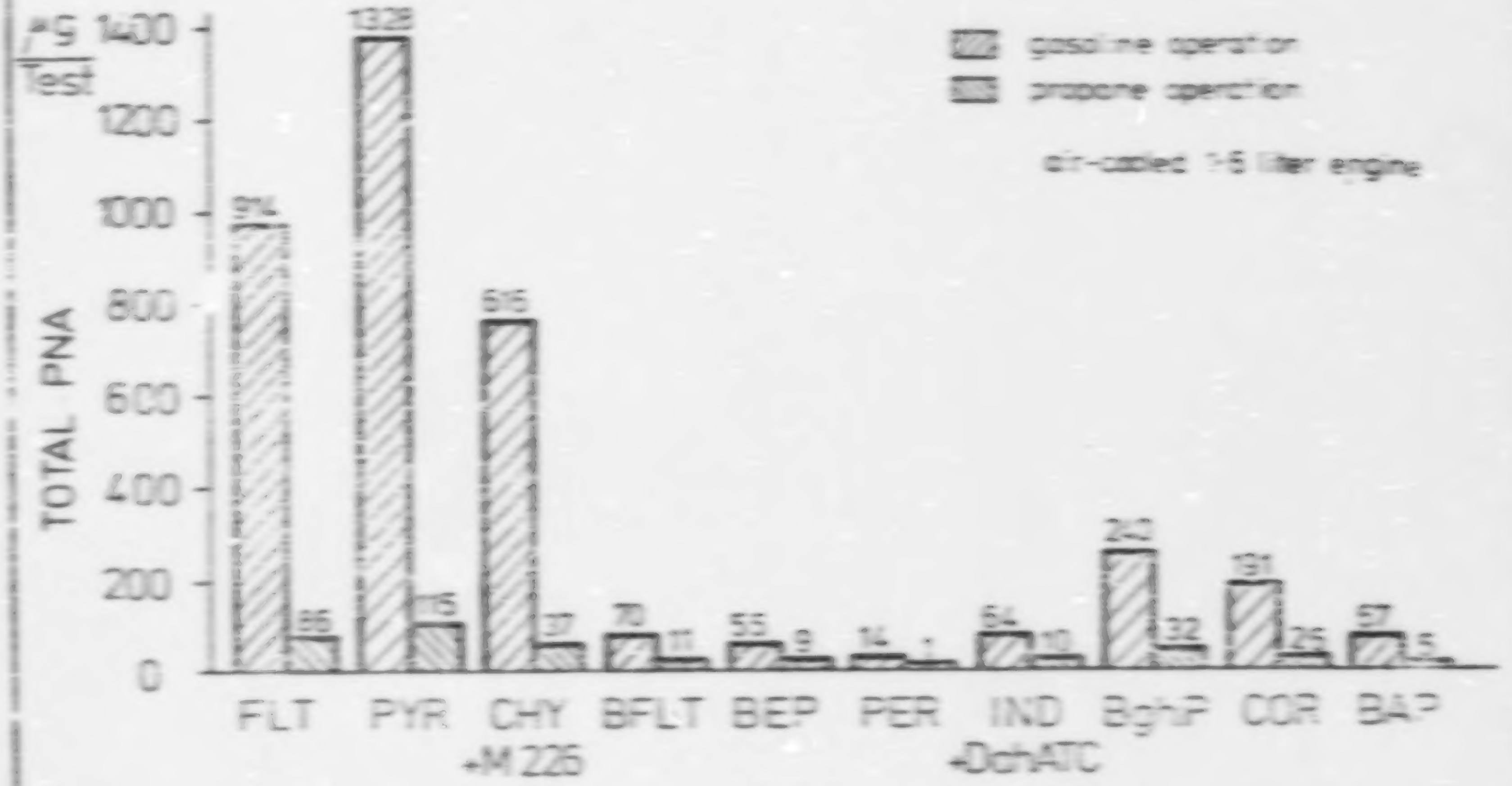
On the other hand, engines operated on methanol show an extremely strong presence of 80% of the lower four-ring fluoranthene and pyrene components. This means that the absence of the PNAs and of the other aromatics components in methanol fuel not only produces a PNA emission that has been reduced by one order of magnitude but that higher PNA synthesizing is impeded.

(5) The investigation shows the total of the more or less carcinogenic individual components (as far as such carcinogenic effects are known from various sources) to amount to approximately 20% or 30% per volume of total PNA emission.

VW produced another graph (Figure VW-2) which shows the results obtained with an engine using propane and gasoline. VW notes that propane operation reduces the PNA content to 10% (similar to methanol operation) when compared with gasoline operation.

VW feels this fact permits an interesting conclusion in regard to the influence of engine oil, i.e. that engine oil influence on PNA emissions in gasoline operation is bound to be lower than 10%. VW stated, it is of additional interest that identical hydrocarbon emissions were measured in the European Test Procedure under both modes of operation. They feel this confirms the experience found elsewhere in a great many areas that

Figure 18-2



TOTAL PNA EMISSION-GASOLINE VERSUS PROPANE OPERATION the level of hydrocarbon emissions can not be used to draw conclusions about PNA emissions.

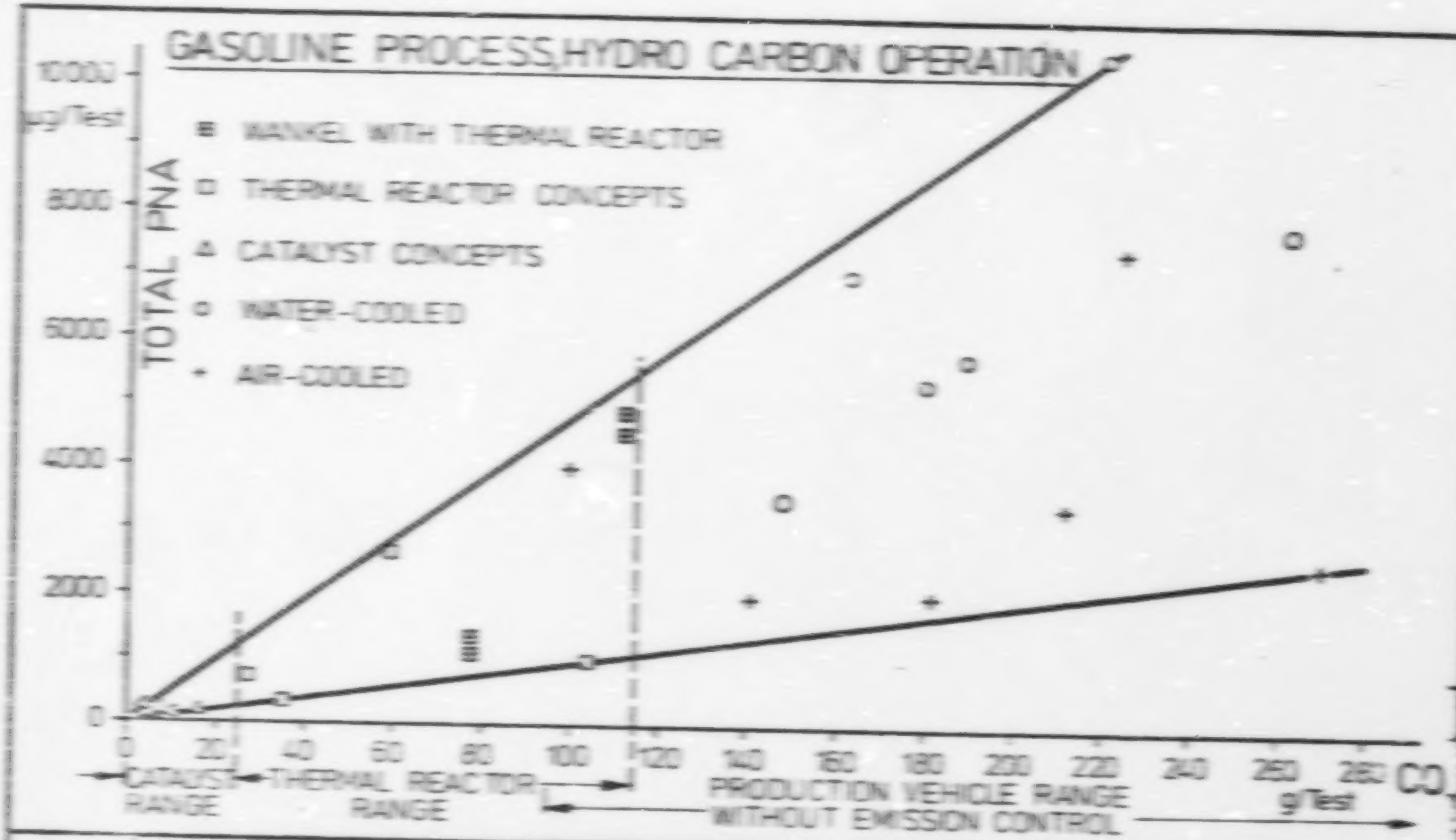
Another interesting graph (Figure VE-9) from VW presents the PNA emissions compared to CO emissions. This graph shows the results obtained from different gasoline engine equipped vehicles. Each point represents one test vehicle. The graph allows for the following VW findings:

> All measuring points are located in a band that spreads with the increase in CO emissions, and the upper limit of which is set by the ascending slope of approximately 5000 μgm PNA/100 gm CO and the bottom limit by 1000 μgm PNA/ 100 gm CO.
>
> Water-cooled engine equipped production vehicleu produce a much higher PNA emission than do air-cooled engine equipped production vehicles.
>
> The distinguishing characteristics between water-cooled and air-cooled system are futher affected by additional engine characteristics. Nevertheless, it does not appear to be unrealistic to expect the markedly cooler combustion chamber walls in water-cooled engines to tend to produce higher PNA emissions because these close-to-the-wall zones with their inherent incomplete combustion due to wall-quenching, must be considered highly responsible for the production of PNA emissions. These quench zones also tend to be greater in water-cooled engines.

6.3.3. Conclusions

The VW work confirms earlier work done by Exxon and UOP which shows about 9% of the amount of PNA from non-catalyst cars is found in catalyst cars. VW also showed that use of methanol as an alternate fuel reduces PNA emissions and causes different types of PNAs to be emitted.

Figure III-3



PNA EMISSIONS AS FUNCTION OF CO-EMISSION,IN EUROPE-TEST

An important area not addressed by any of the manufacturers is PNA emissions from light duty Diesels. With the planned introduction of the VW and Oldsmobile Diesels, this area is important.

6.6. Diesel Particulate Emissions

6.6.1. Introduction and Background

Mobile sources contribute a small but still significant part of the total suspended particulates in ambient air. For example, prior to the introduction of unleaded fuel, automobiles using leaded fuels contributed between 2 and 13% of the total suspended particulates in urban areas. With about half of the air quality control regions around the country over the total suspended particulate air quality standard of 75 $\mu g/m^3$ automotive particulate emissions are important to the attainment of the total suspended particulate standard.

With vehicles burning fuel with maximum lead concentrations (containing about 2.5 gm lead/gal), the resultant particulate emissions are 0.25 gm/mi. On the other hand, a non-catalyst vehicle burning unleaded fuel emits only 0.01 gm/mi of particulate. Catalyst equipped vehicles emit much less particulate than vehicles burning leaded fuel but more particulate than non-catalyst vehicles burning unleaded fuel. An approximate particulate emission rate for these catalyst cars is 0.02 gm/mi and is based on testing of over 100 cars. Particulates from non-catalyst vehicles burning unleaded fuel consist mostly of high molecular weight organic compounds. Particulates from catalyst cars burning unleaded fuel consist primarily of sulfuric acid and its water of hydration.

As the use of unleaded fuels in catalyst equipped vehicles displaces the use of leaded fuels (which emit 0.25 gm/mi particulates), the automotive contribution to urban air total suspended particulates will decrease from 2-13% to about 0.2-1.3%.

The introduction of large numbers of light duty Diesels may reverse this trend and increase the automotive contribution to total suspended particulates. Therefore, it is important to investigate the quantity of Diesel particulates emitted.

6.6.2. Composition of Diesel Particulates

The composition of light duty Diesel particulates has not been completely determined. It is known that a major constituent of these particulates is elemental carbon with the ability to adsorb other compounds on it much like activated charcoal. The types of compounds that have been found adsorbed are SO_2, sulfate, high molecular weight organic compounds, and polynuclear aromatic hydrocarbons.

The quantity of hydrocarbons including polynuclear aromatics (PNA) present in Diesel particulates is currently being investigated by EPA in contracts with Southwest Research Institute (SwRI). A problem impeding progress in this area is that the sampling and collection procedures are in a rudimentary stage of development, particularly for PNA. Some measurements are currently being conducted for one PNA species, benzo(a)pyrene, in light duty Diesels under the EPA contract work with SwRI. Also, PNA emissions were investigated to some extent by a previous CRC contract with Gulf Research.

The amount of sulfate in Diesel particulate has been determined accurately by EPA work (both in-house and contract work) and found to represent only a small fraction (about 1-2%) of the sulfur in Diesel fuel. While this conversion to sulfate is about the same for the Diesel as for non-catalyst gasoline cars, Diesel sulfate emissions are greater than those from non-catalyst gasoline cars (0.1 vs. 0.01 gm/mi) due to the higher sulfur content of Diesel fuel compared to gasoline (about 0.23% vs. 0.03%). Still, sulfate emissions account for a very small part of the total particulates from Diesels.

There is some overlap between Diesel particulate and hydrocarbon measurements. Some of the compounds measured as gaseous hydrocarbons by the heated FID (at 375°) used in the Federal Test Procedure are also collected as particulates since the dilution tunnel filter is about 120°F. The amount of overlap has not been quantified accurately, but some fraction of the particulate is being measured and subject to the HC emissions standards.

Diesel particulates are very small in size with most of the Diesel particulates below 1 micron in size. Attempts to determine the size distribution by impactors have not been successful since impactors separate particulates from 1 to 10 microns in size. This information on particulate sizes is important to the determination of how far they penetrate into the respiratory system.

The health effects associated with Diesel particulates have not been determined. EPA has a contract with SwRI to do some bioassay tests on Diesel particulates and is also doing some in-house animal tests in Cincinnati.

6.6.3. Quantity of Diesel Particulates

Almost all of the work done to obtain emission factors on light duty Diesels has been done by EPA either through contract or in-house testing. Little data have been provided by the manufacturers.

These programs have employed the standard dilution tunnel approach to measurement. Tests completed to date have included the vehicles shown in Table 6-16. The results are also shown in the table.

The Oldsmobile prototype tested by EPA is similar to but not identical to the version being considered by GM for production in 1978. EPA contract work at SwRI involved testing a number of Diesel vehicles.

Particulate emissions rates are given for several cycles including the FTP, CFDS, and FET. Of special interest are the FTP results, since this driving schedule represents driving patterns in an air quality control region as a whole. Since gaseous emissions over the FTP are used in air quality models and for emission factors in the EPA booklet AP-42, particulate emission factors over the FTP can be used likewise. The CFDS represents congested freeway driving while the FET represents rural highway-type driving.

The Mercedes 300D was tested by both SwRI and EPA. The particulate results obtained by EPA (0.43, 0.27, 0.25 gm/mi over the FTP, CFDS, and FET) agree well with those obtained by SwRI, (0.49, 0.37, and 0.39 gm/mi over the FTP, CFDS and FET). The gaseous emission numbers also agree well. The same Oldsmobile Diesel was also tested at both labs but EPA did not obtain particulate mass measurements during the tests. The particulate numbers on the VW Diesel from SwRI (0.29, 0.26, and 0.25 gm/mi over the FTP, CFDS, and FET) agree well with those obtained by EPA (0.32, 0.23, and 0.26 gm/mi over the FTP, CFDS, and FET). The gaseous emission results between the two laboratories on the VW agree reasonably well, but the HC at EPA (0.11 gm/mi) is lower than that found at SwRI (0.37 gm/mi).

Table 4-16

Particulate Emission Rates of Light-Duty Diesel Vehicles

	Vehicle/Model	Engine Disp. (CID)	Inertia wt (lbs)	Test Lab	FTP Gaseous Emissions HC g/mile	CO g/mile	NOx g/mile	Sulfates mg/mile SET	Particulates g/mile FTP	SET	HFET	Fuel Eco. (MPG) HFET	FTP
1.	Mercedes 220D	134	3500	SwRI	0.18	1.36	1.05	9.21[1]	0.66	0.43	0.38	33.5	25.9
2.	Mercedes 240D	146	3500	SwRI	0.29	0.97	1.27	14.12[1]	0.40	0.36	0.31	33.7	25.7
3.	Mercedes 300D	183	4000	SwRI	0.16	0.85	1.72	26.51[1]	0.49	0.37	0.39	30.0	23.8
4.	Peugeot 204D	83	2500	SwRI	1.11	1.71	0.68	8.21[1]	0.38	0.24	0.30	43.8	35.9
5.	Perkins 6-247	247	4500	SwRI	0.72	2.67	1.50	16.36[1]	0.81	0.49	0.54	28.3	25.7
6.	VW Diesel*	90	2250	SwRI	0.37	0.79	0.87	7.02	0.25	0.26	0.25	53.7	42.7
6a.	VW Gasoline			SwRI	0.23	3.78	1.01	1.65	0.007	0.002	0.003	36.1	24.6
7.	Oldsmobile Diesel	350	4500	SwRI	0.76	2.00	1.13	16.62	0.92	0.59	0.48	2	2
7a.	Oldsmobile Gasoline*	350	4500	SwRI	0.38	2.16	1.57	20.98	0.009	0.016	0.021	23.0	15.5
8.	Pinto Diesel		2750	GM	0.24	1.21	0.76	4.53	0.35	0.30	0.28	56.5	44.8
9.	Postal Van Diesel	165	3000	GM	0.14	1.47	2.56	10.24	0.47	0.27	0.24	37.8	29.9
10.	VW Rabbit Diesel	90	2250	GM	0.11	0.98	1.22	9.34	0.32	0.23	0.26	51.9	31.6
11.	Chrysler Diesel	238	4500	GM	0.26	1.22	1.82	12.24	0.29	0.17	0.17	25.7	22.4
12.	VW Rabbit Diesel	90	2250	GM	0.23	1.11	0.55	5.47	0.31	0.20	0.20	51.7	40.6
13.	Mercedes 300D	183		GM	0.26	0.92	2.17	7.85	0.43	0.27	0.25	29.5	23.8
14.	Oldsmobile Diesel	350	4500	GM	0.52	1.92	1.47	8.52		0.42	0.38	2	2
15.	Nissan Diesel	122	3500	EPA	0.25	1.10	1.37		0.3		0.33	33.8	26.2
16.	Peugeot 504	129	3000	EPA	0.49	1.45	2.30	7.0	0.51	.31	0.40	35.4	26.4

---

*Gasoline car included for comparison to diesel counterpart.

[1] Sulfate values for these tests are over the FTP.

[2] GM requested the diesel fuel economy for the Oldsmobile be kept confidential at this time.

The four tests on the three Mercedes vehicles tested gave an average particulate mass of 0.50 gm/mi over the FTP. The two Peugeot vehicles tested gave 0.45 gm/mi of particulate over the FTP. The Nissan had particulate emissions of 0.30 gm/mi. The VW Rabbit Diesel also had particulate emissions of 0.30 gm/mi. This level of particulate emissions is still over 40 times the level found from the VW gasoline prototype. The Oldsmobile Diesel emitted a relatively high level of particulates (0.92 gm/mi over the FTP). This level is 100 times the level found from the gasoline counterpart (an Oldsmobile 350 gasoline vehicle). However, GM states that this Oldsmobile Diesel is a prototype and may be changed before final production.

The two gasoline counterparts (Oldsmobile and VW) had somewhat lower particulate emissions than found for vehicles equipped with catalysts general (0.02 gm/mi). The 0.02 gm/mi number is based on extensive tests of over a hundred cars and should be considered a number for general comparison of gasoline and Diesel cars. For individual models, it is more appropriate to use numbers from Diesel-gasoline counterparts if available.

The average particulate emissions from the four tests on the three Mercedes, the two tests on the VW, the test on the Oldsmobile, the two Peugeots, and the Nissan are about 0.5 gm/mi over the FTP. The number can be used as an approximate Diesel particulate emission factor for air quality models. It can be updated as more data are available. The numbers from the experimental vehicles (Pinto, Postal Van, and Chrysler Diesels) were not included in this average but would not significantly change it.

6.6.4. Conclusions

Tests conducted to date show very high particulate emissions from light duty Diesels (0.5 gm/mi) which is about 25 times comparable values for gasoline vehicles equipped with catalysts (about 0.02 gm/mi).

These particulates consist of elemental carbon as well as various hydrocarbon compounds and small quantities of sulfate. EPA does not know yet what the health effects of these particulates are.

SECTION 7

INDIVIDUAL MANUFACTURER REVIEWS

7.1. Domestic Manufacturers

7.1.1. American Motors

7.1.1.1. Systems Under Development

American Motors is currently planning to continue using powerplants built basically from current engine tooling for the 1978 through 1985 model years, thus their present emission control system development efforts are directed toward internal combustion, reciprocating, four stroke, gasoline fueled engines.

Oxidation Catalysts

Pelleted type oxidation catalysts are currently being considered by AMC for use on all 4, 6, and 8 cylinder engines in meeting the near term Federal emissions standards. To meet near term California emissions standards, AMC uses monolithic start catalysts on the 6 and 8 cylinder engines with the 8 cylinder engine having two monolithic start catalysts and two pelleted catalysts. These catalysts are described in Table AMC-1.

AMC has recently started testing on three improved underfloor oxidation catalysts. These catalysts are supplied by AC Spark Plug. They are all 160 cu in. pelleted catalysts. One of these has a 0.05 troy ounce loading with a 71% Pt/29% Pd compositon but, AMC apparently does not know the loading or composition ratio of the others. They are testing these catalysts with and without the above described monolithic start catalysts. These systems are described in Table AMC-2.

Table AMC-1

AMERICAN MOTORS OXIDATION CATALYSTS

	Main Catalyst	Start Catalyst
Type	Oxidation	Oxidation
Substrate =	Pellet	Monolith
Volume =	160 cu in.	21.5 cu in.
Composition =	71% Pt/29% Pd	67% Pt/33% Pd
Loading =	0.05 troy ounces	0.02 troy ounces
Location =	Underfloor	At Exhaust Manifold
Cat. Supplier =	Engelhard	Engelhard
Canner =	AC Spark Plug	Maremont

Table AMC-2

AMERICAN MOTORS IMPROVED OXIDATION CATALYST VEHICLES

Vehicle Model:	Pacer	Pacer	Pacer
Vehicle Number:	D76-46C and D76-47C	D76-76C and D76-78C	D76-50C and D76-51C
Inertia Weight:	3500 lbs	3500 lbs	3500 lbs
Engine/Carb:	258 CID 6 cylinder/2V		
Ignition System:	Electronic Breakerless	Electronic Breakerless	Electronic Breakerless
Transmission:	Auto	Auto	Auto
Axle Ratio:	3.08:1	3.08:1	3.08:1
Catalyst System:	Monolith Start Cat	Monolith Start Cat	No Start Cat
	23 cu in. 67% Pt/33% Pd 0.02 t.o.	23 cu in. 67% Pt/33% Pd 0.02 t.o.	
	Underfloor Pellet	Underfloor Pellet	Underfloor Pellet
	160 cu in. 71% Pt/29% Pd 0.05 t.o.	160 cu in. Loading and Ratio Unknown	160 cu in. Loading and Ratio Unknown
Air Injection:	belt driven vane type air pump, exh port injection	belt driven vane type air pump, exh port injection	belt driven vane type air pump, exh port injection
EGR:	carb port vac exh B/P mod valve	carb port vac exh B/P mod valve	carb port vac exh B/P mod valve

		HC	CO	NOx	MPG_U	HC	CO	NOx	MPG_U	HC	CO	NOx	MPG_U
0 mi	Veh #1	0.61,	1.2,	1.48,	11.5	0.39,	4.7,	0.84,	11.2	0.47,	6.3,	1.24,	12.6
	Veh #2	0.38,	2.1,	1.28,	11.4	0.46,	4.2,	1.51,	12.65	0.51,	4.8,	1.19,	11.6
5000 mi	Veh #1	---				0.43,	3.1,	1.11,	12.0	---			
	Veh #2	0.46,	3.5,	1.24,	12.8	0.41,	4.3,	1.36,	12.9	---			
10,000 mi	Veh #1	---				0.55,	4.9,	1.08,	13.3	---			
		---				0.52,	4.9,	1.32,	12.7	---			

3-Way Catalysts

AMC is investigating a 3-way catalyst system using closed loop air-fuel ratio control on a Pacer equipped with a 6 cylinder engine. They are evaluating two different oxygen sensors (Bosch and AC) plus pelleted and two-biscuit monolithic catalysts with air injection between the two monolithic catalysts. The vehicle is described in Table AMC-3. Best results to date have come from the AC O_2 sensor and Maremont two-biscuit monolithic catalyst.

Table AMC-3

CLOSED LOOP 3-WAY CATALYST VEHICLE

Vehicle Model:	Pacer
Vehicle Number:	P66 - 63K
Inertia Weight:	3500 lbs.
Engine:	6-cyl. 258 CID
Fuel System:	Carter 1V Carb with exh O_2 feedback control
Intake:	Cast iron EFE
Exhaust:	6-port cast iron with bi-metal control exh heat valve
Ignition system:	Electronic breakerless
Transmission:	Auto
Axle Ratio:	3.08:1
Catalyst System:	160 cu in. pellet or dual biscuit monolith
Air Injection:	Belt driven vane type (two biscuit cat. only)
EGR:	None
Oxygen Sensor:	Bosch or AC

Best emission levels have been 0.28 HC, 1.0 CO, 0.70 NOx, 14.1 MPG_u with levels typically being about 0.3 HC, 1.8 CO, 0.74 NOx, 16 MPG_u with this vehicle. AMC judges these results as encouraging against a 2.0 NOx standard but concludes that it falls short of the targets required to achieve 0.41 HC and 3.4 CO standards.

3-Way Plus Oxidation Catalysts

AMC currently projects that a 3-way plus oxidation catalyst system will be used on their 6 and 8 cylinder engines to meet emission levels of 0.41 HC, 3.4 CO, and 1.0 NOx and on their 4 and 6 cylinder engines to meet 0.41 HC, 3.4 CO, and 0.4 NOx.

Durability testing (SOHIO Courtesy Fleet Program) was conducted on four vehicles - two equipped with Walker and two with Maremont 3-way plus oxidation catalyst systems. These vehicles are described in Table AMC-4. Both systems used carburetors calibrated to flow roughly constant air-fuel ratios rather than a closed loop control system. Though the Maremont systems performed slightly better, the four vehicles were unable to achieve AMC's target emission level of 0.41 HC, 9 CO, 1.0 NOx. One of the Maremont equipped vehicles finished the 50,000 mile durability test at 0.42 HC, 7.4 CO, 0.72 NOx, 13.0 MPG_u. Vehicle system problems unrelated to the catalyst systems such as sticking fresh air opening ducts in air cleaner snorkels and burned out choke gaskets caused some of the excessive CO levels on two vehicles. Throttle cable sticking was noted on all four vehicles early in the testing due to dust shield deterioration but no effect on emissions was indicated by AMC. Other problems included two vehicles with cracked exhaust manifolds at 31,711 and 39,023 miles but no problems occurred in the exhaust system or catalyst components. Table AMC-5 shows the catalyst conversion efficiencies at the beginning and end of durability testing. Most of the catalyst systems retained good HC and CO conversion efficiency. NOx conversion efficiencies were less predictable and the variability could not be explained by AMC.

Table AMC-4

SOHIO Fleet 3-Way Plus Oxidation Catalyst Vehicle Descriptions

Vehicle	Matador w/258 CID w/Quench Combustion Chamber
Test Inertia	4000 lbs
Trans/Axle Ratio	Auto/3.08:1
Ignition System	Distributor - #106 Motorcraft Spark plugs - N12Y (.035" gap) Idle RPM - 700 in drive Timing - 8° BTDC (160°F CTO* spark override)
EGR System	Back pressure modulated (115°F CTO EGR override)
Air Injection	Air to exhaust manifold until 115°F CTO switches air to catalyst
Carburetor	Carter BBD 2V with 92 MMJ and special metering rod. Typical A/F ratio as follows:

Speed (MPH)	A/F	Man Vac (in Hg)
Idle	14.0	14.2
10	14.6	16.2
20	14.5	14.6
30	14.7	14.0
40	14.8	11.0
50	14.8	10.8
60	14.4	5.0
60	14.2	4.0
60	14.0	3.0
60	13.5	2.0

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* CTO = coolant temperature override

Table AMC-5

SOHIO Fleet - 50 MPH 3-Way Plus Oxidation Catalyst Conversion Efficiencies

			BEFORE CONVERTER			AFTER CONVERTER			50 MPH S.S. EFFICIENCY		
Veh. #	Catalyst Canner	MILES	HC ppm	CO %	NOx ppm	HC ppm	CO ppm/%	NOx ppm	HC %	CO %	NOx %
#57	Walker	52	600	2.42	1400	13.5	362.4p*	40.5	97.5	98.6	71.1
		42825	1420	4.18	505	1075	3.62%	458	23.7	13.4	9.3
		47449	1300	5.3%	158	180	2.72%	126	86.2	48.5	20.3
#58	Walker	41	300	2.53	133.7	10	1125p	68.5	96.7	96.0	49
		32352	1300	4.38	225	280	2.14%	145	94.6	51.1	35.6
		39092	1309	5.36	177	160	2.20%	141	87.7	58.9	20.3
		48397	1043	0.80	252	135	0.04%	48	87.0	95.0	80.9
#42	Maremont	44	700	2.58	138.7	15.5	884.1p	75.5	97.8	96.6	46
		40245	910	2.86	192	50	2.28%	97	94.5	19.7	49.6
		49625	1200	1.0	223	60	0.04%	140	94.3	96.0	37.2
#43	Maremont	45	400	0.81	250	33.0	163.1p	32.0	91.8	98.0	87.2
		16880	1400	5.82	84	270	2.36%	60	80.7	59.5	28.6
		23427	1200	1.85	82	200	0.16%	53	83.3	91.4	35.4
		31712	1040	2.27	90	190	0.10%	63	81.4	95.6	25.7
		40506	1350	2.40	94	200	0.06%	69	85.2	97.5	26.6

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* p = ppm

Dual Catalysts

The Gould dual catalyst program has been terminated by AMC. Two vehicles, originally equipped as 1977 California cars with carburetor modifications to maintain a 14.0 A/F ratio, were involved in the program with the only difference being the use of a pelleted oxidation catalyst on one vehicle with a monolith on the other. Overall HC and CO results were somewhat better with the monolith but AMC seems unconvinced that this may be due to faster warmup characteristics as compared to the pelleted catalyst. After witnessing high nickel particulate emissions using 0.03% versus 0.01% sulfur fuel, AMC concluded that the presence of sulfur in the fuel attacks the nickel in the reducing catalyst and would eventually destroy its reducing efficiency. These systems are described in Tables AMC-6 and AMC-7 and results from the concluding tests are presented in Table AMC-8.

Other Systems

Some development work has been done on a Bendix programmed electronic breakerless ignition system installed in a 6 cylinder, 232 CID Pacer. Test data seem to indicate potential fuel economy benefits, however, more optimization work appears necessary.

AMC is expected to expand their engine mapping efforts in conducting multi-parameter engine optimization studies. They apparently are not now utilizing a computer in their data analysis but anticipate the need for one along with associated test equipment and additional manpower. In view of their projected future use of programmed spark, EGR, air injection, and carburetor operation through a central digital microprocessor, the lack of adequate computing facilities could be a problem.

Table AMC-6

GOULD DUAL CATALYST

VEHICLE	050-2L (M)	
TARGET STANDARDS	0.41 HC, 3.4 CO, and 0.40 NOx - 1978 statutory	
TEST INERTIA	3500 lbs.	
N/V	42.5 with a 3.08:1 axle ratio	
TRANSMISSION	Automatic, 3 speed	
ENGINE TYPE	6 cylinder, inline, reciprocating	
DISPLACEMENT	258 C.I.D. with revised 1977 combustion chamber	
CARBURETOR	1976 1V with modified metering to achieve 14.0 A/F ± 0.5 at part throttle	
CHOKE	Bimetal, hot air control with electric assist	
INTAKE MANIFOLD	1976 Hot Spot Manifold	
EGR SYSTEM	Backpressure regulated with 115°F coolant over-ride 10 in H_2O sensor and .410 EGR orifice plate	
EXHAUST MANIFOLD	1976 production	
IGNITION SYSTEM	1976 breakerless, modified curve with 8° BTDC initial	
VACUUM ADVANCE CONTROL	1976 California TCS-above 35 mph only. Dist. vacuum advance controlled by a 160°F coolant switch.	
CATALYST TYPE	GEM 68 REDUCING	OXIDATION-UNDERFLOOR
a. Active Material	Nickel alloy	1975-76 production A. C. Spark Plug Model 160
b. Loading	non-noble metals	
c. Substrate Structure	Wire Mesh	
d. Manufacturer	Gould, Inc.	
e. Canner	Gould, Inc.	
f. Volume	110 cu in. Getter = 40 cu in.; Red. = 70 cu in.	
AIR INJECTION	19 CID Vane Pump at 1:1 ratio	
a. Supplier	Saginaw Steering Gear	
b. Modulation	Production diverter valve removed	
c. Injection Location	Exhaust manifold cold; oxidizing converter inlet hot	
d. Switching Control	160°F engine coolant switch to RPD air switching valve	

Table AMC-7

GOULD DUAL CATALYST

VEHICLE	D50-4L (K)	
TARGET STANDARDS	0.41 HC, 3.4 CO, 0.40 NOx 1978 Statutory	
TEST INERTIA	3500 lbs.	
N/V	41.0	
TRANSMISSION	Automatic, 3-speed	
ENGINE TYPE	Inline, reciprocating, 6-cylinder	
DISPLACEMENT	258 CID revised 1977 combustion chamber	
CARBURETOR	1976 1V with modified metering to achieve 14.0 A/F ± 0.5 at part throttle	
CHOKE	Bimetal, hot air control with electric assist	
INTAKE MANIFOLD	1976 Hot Spot Manifold	
EGR SYSTEM	Backpressure regulated with 115°F coolant over-ride 10 in H_2O sensor and .310 EGR orifice plate	
EXHAUST MANIFOLD	1976 production	
IGNITION SYSTEM	Breakerless, 1976 modified with 8° BTDC initial	
VACUUM ADVANCE CONTROL	1976 California TCS-above 35 mph only. Vacuum advance controlled by a 160°F coolant switch	
CATALYST TYPE	GEM 68 REDUCING CONVERTER	OXIDIZING CONVERTER
a. Active Material	Nickel alloy	Platinum/Palladium
b. Loading	Non-noble metals	0.095 Troy ounces
c. Substrate Structure	Wire mesh	Monolith
d. Manufacturer	Gould, Inc.	Engelhard Inc.
e. Canner	Gould, Inc.	Maremont Corp.
f. Volume	110 cu in. GETTER = 40 cu in.; RED. = 70 cu in.	102 cu in. total
AIR INJECTION	19 CID vane pump at 1:1 ratio	
a. Supplier	Saginaw Steering Gear	
b. Modulation	Production diverter valve removed	
c. Injection Location	Exhaust ports cold; oxidizing converter inlet hot	
d. Switching Control	160°F engine coolant switch	

Table AMC-8

GOULD DUAL CATALYST - CONCLUDING TESTS

258-2L (K) (AC-Gen 68)

	HC	CO	NOx	MPG
		(grams/mile)		
Baseline (AMC Lab)*	.329	4.42	1.59	13.7
Baseline (Gould Lab)*	.44	5.97	1.12	13.6
NOx catalyst				
installed (750 miles)	.35	3.26	.55	13.5
Run #2	.37	2.92	.53	13.3
(Gould Lab)	.36	3.09	.54	13.4
Recheck (AMC Lab)	.452	2.60	.542	13.8
Recalibrate for				
driveability and MPG				
-Index 1 lean (was 4 lean)				
New air switching valve				
New air cleaner				
2.75 amls.				
New heat tube				
	.568	4.29	.547	14.7
	.522	3.21	.527	14.6
	.545	3.75	.537	14.6
6072 Test Miles	.446	3.63	.427	14.4
	.561	4.28	.565	14.6
	.503	3.96	.501	14.5
11,000 Test Miles	.48	3.6	.52	14.7
	.46	3.0	.48	15.6
	.47	3.3	.50	15.1
16,000 Test Miles	.81	8.2	.52	14.6
	.48	4.1	.53	14.9
	.65	6.1	.52	14.7

258-4L (K) (Pacesetter - Gen 68)

	HC	CO	NOx	MPG
		(grams/mile)		
Baseline*	.381	1.97	1.38	14.5
Run #7	.338	1.50	1.62	14.5
Average -	.359	1.75	1.50	14.5
NOx catalyst	.204	1.71	.751	—
installed	.285	0.90	.686	14.7
Average -	.244	1.30	.718	14.7
60 Miles	.328	3.11	.511	14.5
3014 Miles	.375	3.41	.482	13.6
Run #2	.367	3.28	.433	14.5
Average -	.371	3.34	.458	14.1
8221 Miles	.296	1.66	.796	15.9
Run #2	.351	3.27	.853	15.7
Run #3	.334	3.02	.727	15.1
Average -	.327	2.64	.791	15.5
New air	.423	4.56	.962	15.0
switching valve	.392	2.78	1.05	14.7
(9400 miles) Avg.	.407	3.67	1.01	14.9
Baseline*	.220	4.0	1.97	15.1
Recheck	.220	2.6	2.07	15.2
Average -	.220	3.3	2.02	15.2

* 1977 California specification with carburetor modification to 14.0:1 A/F ratio.

Other Development Efforts

Three vehicles equipped with lean burn systems are currently being studied by AMC. These are described in Table AMC-9. The test data from these vehicles indicate a potential for achieving a 0.41 HC, 3.4 CO, 2.0 NOx standard. Substantial improvement in NOx control is needed for this system to meet a 1.0 or lower NOx level, and increases in catalyst volume may be needed to maintain HC and CO control at high mileage.

7.1.1.2. Systems to be Used at Various Emission Levels

AMC's choices of systems to be used at various emission levels are presented in Tables AMC-10 through AMC-15. At the 0.41 HC, 3.4 CO, 2 NOx level AMC is considering three alternatives which will be dependent upon the availability of vendor prototype hardware, vendor engineering assistance, and production units. For statutory emission levels, AMC has not yet projected what systems will be used on their 8 cylinder engines.

The estimated future retail costs for the systems to be used by AMC to meet various emission levels occurring in various years compared to previous years are presented in Tables AMC-16 through AMC-18. The cumulative costs for these systems compared with AMC's 1977 emission control systems are shown in Table AMC-18. To meet statutory emission levels sometime after 1981 with their 6-cylinder engines, AMC estimates that it will cost the consumer approximately $538 over the price of their 1977 6 cylinder models. All the costs shown in these tables represent approximately a 17% markup over dealer costs.

7.1.1.3. Durability Testing

Normally, AMC does not conduct any durability testing until the systems chosen are reasonably near final design. Some data are available, however, for three out of four of AMC's 1977 California durability fleet and for four 3-way plus oxidation catalyst vehicles in the DOHIO fleet described in Table AMC-6. These data are presented in Tables AMC-19 and AMC-20.

Table [illegible]

[illegible]

Vehicle Model:	Horizon	Horizon	Horizon
Vehicle Number:	[illegible]	[illegible]	[illegible]
Inertia Weight:	[illegible] lbs	[illegible] lbs	[illegible] lbs
Engine:	4-cylinder, OHC, [illegible] CID	4-cylinder, OHC, [illegible] CID	4-cylinder, OHC, [illegible] CID
Fuel System:	2V carburetor	2V carburetor	2V carburetor
Intake:	Cast iron, EGR, exhaust heat	Cast iron, EGR, exhaust heat	Cast iron, EGR, exhaust heat
Exhaust:	4-port, cast iron, bi-metal control heat valve	4-port, cast iron, bi-metal control heat valve	4-port, cast iron, bi-metal control
Ignition System:	Chrysler electronic programmed spark control	Chrysler electronic programmed spark control	Chrysler electronic programmed spark
Transmission:	3-speed automatic	3-speed automatic	4-speed manual
Axle Ratio:	[illegible]	[illegible]	[illegible]
Catalyst System:	45 cu. in. oxidizing monolith	45 cu. in. oxidizing monolith	45 cu. in. oxidizing monolith
Air Injection:	None	None	None
EFE:	None	None	None

	HC	CO	NOx	MPG_U	MPG_H	HC	CO	NOx	MPG_U	MPG_H
Selected Low Mileage Test Results (Gram/Mile)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
	[illegible]	[illegible]	[illegible]	[illegible]	-					

Table [illegible]

[illegible]

	4-cyl.	6-cyl.			8-cyl.	
	1st Concept	1st Concept	Concept	Baseline	Concept	Baseline
Engine	121 CID	231, 250 CID	231, 250 CID	250 CID	[illegible] CID	[illegible], 350 CID
Engine Modifications	carryover '77	c/o '77	c/o '77	c/o '77	c/o '77	c/o '77
Inertia Weight	2750, 3000 lbs	3000, 3500 lbs	3500 lbs	4000 lbs	4500 lbs	4500 lbs
Transmissions	4 spd man, 3 spd auto	3 & 4 spd man, 3 spd auto	3 & 4 spd man, 3 spd auto	3 spd auto	3 spd auto	3 spd auto
Fuel Supply and [illegible]	[illegible]	[illegible]			[illegible]	
[illegible]	[illegible]	[illegible]			[illegible]	
Ignition System	breaker points with mech and vac adv	electronic breakerless with mech and vac adv			elect. breakerless with mech and vac adv	
EGR System	spark port vac control	spark port vac and [illegible] control			[illegible] port vac and [illegible] control	
Air Injection	belt driven vane type pump, port injection	belt driven vane type pump, port injection			belt driven vane pump, port injection	
Catalysts	oxidation, pellet, underfloor	with and without underfloor oxidation	with and without underfloor oxidation	oxidation pellet, underfloor	oxidation, pellet, underfloor	
Evap. System	closed fuel system, tank and carb vented to induction system purge activated charcoal canister	closed fuel system, tank and carb vented to induction system purge activated charcoal canister			closed fuel sys, tank and carb vented to [illegible] purged [illegible] charcoal can	

Table ANC-11

EMISSION CONTROL SYSTEMS FOR 1978 - 0.41 HC, 9 CO, 1.5 NOx, 6 EVAP

	4-cyl	6-cyl		8-cyl	
	Sub Compact	Sub Compact	Mid/Large	Compact	Mid/Large
Engine	122 CID	250 CID	250 CID	304 CID	360 CID
Engine Modifications	c/o '77	c/o '77	c/o '77	c/o '77	c/o '77
Inertia Weight	3000 lbs	3500 lbs	3500 lbs	4000 lbs	4500 lbs
Transmission	4 spd man, 3 spd auto	4 spd man, 3 spd auto	4 spd man, 3 spd auto	3 spd auto	3 spd auto
Fuel Supply and Induction	staged 2V carb, alum H_2O heated intake, TAC	1V, 2V carb, cast iron EFE exh heated int man, TAC		2V carb, cast iron 2-level exh crossover heated int man, TAC	
Exh Man and Ports	4-port cast iron	6-port cast iron, bi-metal heat valve		two 4-port cast iron exh man with bi-metal conduct heat valve	
Ignition System	breaker point with mech and vac adv	electronic breakerless distributor with mech and vac adv		electronic breakerless distributor with mech and vac adv	
EGR System	spark port vac control	spk port vac and exh B/P control		spk port vac and exh B/P control	
Air Injection	belt driven vane type	belt driven vane pump, port injection		belt driven vane pump, port injection	
Catalysts	underfloor oxidizing pellet	underfloor oxidizing pellet with monolith start cat		2 underfloor oxidizing pellet with monolith start cat	2 underfloor oxidizing pellet with 2 monolith start cat
Evap System	closed fuel system, tank and carb vented to induction system purged activated charcoal canister	closed fuel system, tank and carb vented to induction system purged activated charcoal canister		closed fuel system, tank and carb vented to induction system purged activated charcoal canister	

Table [illegible]-12

EMISSION CONTROL SYSTEMS FOR 1979/80 - 0.41 HC, 3.4 CO, 2.0 NOx, [illegible]

	4-cyl		6-cyl (first choice)*		8-cyl
	Sub Compact	Compact	Sub Compact	Compact	Compact
Engine	121 CID	121 CID	231, 250 CID	231, 250 CID	305 CID
Engine Modifications	c/o '78 with hydraulic tappets	c/o '78 with hydraulic tappets	basic '78 c/o, possible new combustion chamber for .X		basic '78 c/o
Inertia Weight	2750, 3000 lbs	3000 lbs	3000 lbs	3500 lbs	4000 lbs
Transmissions	4 spd man, 3 spd auto	4 spd man, 3 spd auto	3 & 4 spd man, 3 spd auto		3 spd auto
Fuel Supply and Induction	staged 2V carb with closed loop fuel control, also H_2O heated int man, TAC		1V, 2V carb with cast iron EFE exh heated int man, TAC		2V carb, cast iron 2-level exh crossover heated int, TAC
Exh Man and Ports	4-port cast iron	4-port cast iron	6-port cast iron with bi-metal controlled exh heat to int		two 4-port cast iron with bi-metal heat
Ignition System	electronic breakerless	electronic breakerless	elect breakerless with programmed spk		elect breakerless with programmed spk
EGR System	none	none	none		spk port vac and exh BP control
Air Injection	none	none	none		belt driven pump port injection
Catalysts	3-way	3-way	improved oxidizing cat		improved oxidizing cat
Evap System	closed fuel system, fuel tank and carb vented to induction system purged activated charcoal canister		closed fuel system, fuel tank and carb vented to induction system purged activated charcoal canister		closed fuel system, fuel tank and carb vented to induction system purged activated charcoal canister

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* See Table [illegible]-13 for second and third choice systems for 6-cyl

Table AMC-13

EMISSION CONTROL SYSTEMS FOR 1979/80 -0.41 HC, 3.4 CO, 2.0 NOx, + EVAP

	6-cyl (second choice)*		6-cyl (third choice)*	
	Sub Compact	Compact	Sub Compact	Compact
Engine	232, 258 CID		232, 258 CID	
Engine Modifications	basic '78 c/s, possible new combustion chamber for 258		basic '78 c/s, possible new combustion chamber for 258	
Inertia Weight	3000 lbs	3500 lbs	3000 lbs	3500 lbs
Transmissions	3 & 4 spd man, 3 spd auto		3 & 4 spd man, 3 spd auto	
Fuel Supply and Induction	2V carb with closed loop fuel control, cast iron EFE exh heated int, TAC		2V carb with closed loop fuel control, cast iron EFE exh heated int, TAC	
Exh Man and Ports	6-port cast iron with bi-metal heat control		6-port cast iron with bi-metal heat control	
Ignition System	electronic breakerless with TCS if required		electronic breakerless with TCS if required	
EGR System	none		none	
Air Injection	none		belt driven pump to downstream ox cat	
Catalysts	new 3-way		new 3-way with downstream ox cat	
Evap System	closed fuel system, fuel tank and carb vented to induction system purged activated charcoal canister		closed fuel system, fuel tank and carb vented to induction system purged activated charcoal canister	

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* See Table AMC-12 for first choice system for 6-cyl

Table AMC-14

Emission Control Systems for 1981 - 0.41 HC, 3.4 CO, 1.0 NOx, 2 Evap

	4-cyl		6-cyl		8-cyl
	Sub Compact	Compact	Sub Compact	Compact	Compact
Engine	121 CID		232, 258 CID		304 CID
Engine Modifications	basic '80 c/s, modifications not determined		basic '80 c/s, possible displacement and other mods		basic '80, modifications not determined
Inertia Weight	2500 lbs	3000 lbs	3000 lbs	3500 lbs	3500 lbs
Transmissions	4 spd man, 3 spd auto		4 spd man with possible O.D., 3 spd auto		improved efficiency 3 spd auto
Fuel Supply and Induction	staged 2V carb with closed loop fuel control, also H_2O heated int, TAC		staged 2V carb with closed loop and fully programmed fuel control thru central digital processor		2V carb with closed loop fully programmed fuel control thru central digital microprocessor
Exh Man and Ports	4-port cast iron		6-port cast iron with bi-metal exc heat		two 4-port cast iron with bi-metal heat control
Ignition System	elect breakerless with programmed spk		elect breakerless with central digital microprocessor programmed control thru multi-inputs including eng spd, load, inlet air temp, baro, H_2O temp, and others		elect breakerless with central digital microprocessor programmed control thru multi-inputs including eng spd, load, inlet air temp, baro, H_2O temp, and others
EGR System	possible spk port vac control		spk port vac and exh B/P control or microprocessor programmed		programmed EGR
Air Injection	none		programmed air injection		programmed air injection
Catalysts	3-way		3-way with downstream ox cat		3-way with downstream ox cat
Evap System	closed loop fuel system, tank and carb bowl vented to 2nd sys purged charcoal canister, improved carb and air cleaner sealing		closed loop fuel system, tank and carb bowl vented to 2nd sys purged charcoal canister, improved carb and air cleaner sealing		closed loop fuel system, tank and carb bowl vented to 2nd sys purged charcoal canister, improved carb and air cleaner sealing

Table AMC-15

EMISSION CONTROL SYSTEMS FOR [illegible] — 0.41 HC, 3.4 CO, 0.4 NOx, [illegible]

	4-cyl Sub Compact	4-cyl Compact	6-cyl Sub Compact	6-cyl Compact	6-cyl Mid/Large	8-cyl
Engine	121 CID		same basic engines as in '81 with possible displacement changes and weight reduction			No Projections Available at this Time
Engine Modifications	not determined		not determined			
Inertia Weight	2500 lbs	3000 lbs	probable 2500 lbs	probable 3000 lbs	probable 3500 lbs	
Transmissions	4 & 5 spd man, improved efficiency lock-up auto		possible multi-speed man with OD and improved lock-up auto			
Fuel Supply and Induction	staged 2V with closed loop and fully programmed fuel control thru central microprocessor, also H2O heated int. TAC, possible fuel injection		staged 2V carb with closed loop and fully programmed fuel control thru central digital microprocessor, possible fuel injection			
Exh Man and Int	4-port cast iron with thermal management		6-port cast iron with controlled exh heat to int with thermal management			
Ignition System	elect breakerless with central microprocessor spk programming		elect breakerless with central digital microprocessor control thru multi-inputs including engine spd, load, inlet air temp, baro, H2O temp, and others			
EGR System	programmed EGR		programmed EGR			
Air Injection	programmed air injection		programmed air injection			
Catalysts	3-way with downstream oxidation catalyst		3-way with downstream oxidation catalyst			
Evap System	closed fuel system, tank and carb bowl vented to 2nd sys purged charcoal canister, improved carb and air cleaner sealing		closed fuel system, tank and carb bowl vented to 2nd sys purged charcoal canister, improved carb and air cleaner sealing			

Table AMC-16

AMC ESTIMATED FUTURE RETAIL EMISSIONS HARDWARE COSTS*
1978 VS 1977

	1.5 HC, 15 CO, 2.0 NOx			0.41 HC, 9 CO, 1.5 NOx		
	4-Cyl (Man & Auto)	6-Cyl (Man & Auto)	8-Cyl (Auto)	4-Cyl (Man & Auto)	6-Cyl (Man & Auto)	8-Cyl (Auto)
Induction System (outside air)	-	2.85	4.56	-	2.85	4.56
Ignition System Revised (Ford Distr)	-	11.99	11.99	-	11.99	11.99
Air Injection System Revision	-	-	-	6.49	-	-
Catalyst: -Underfloor	-	-	-	c/o '77	c/o '77	225.00
-Pre-c.c.	-	-	-	-	48.71	97.41
-Exh. System Revision	-	-	-	-	1.35	2.71
Evap. System -½ port canister	0.54	0.54	0.54	0.54	0.54	0.54
-Carb. mech bowl vent	-	1.69	2.36	-	1.69	2.36
-Add'l hoses, etc.	-	1.01	1.01	-	1.01	1.01
-Aux. fuel trap in bowl vent line	-	-	1.35	-	-	1.46
	0.54	18.08	21.81	7.03	68.14	347.04

* Cost represent approx. 17% over dealer costs.
Dollar basis 1977.

Table AMC-17

AMC ESTIMATED FUTURE RETAIL EMISSIONS HARDWARE COSTS*
1979/80 VS 1978

0.41 HC, 3.4 CO, 2.0 NOx

	First Choice			Second Choice	Third Choice
	4 Cyl (Man & Auto)	6-Cyl (Man & Auto)	8-Cyl (Man & Auto)	6-Cyl (Man & Auto)	6-Cyl (Man & Auto)
Ignition System					
-Microprocessor (Spk Control)	-	68.67	68.67	-	-
-Sensors, misc. elect. cables	-	40.59	40.59	-	-
-Distr., elect. ignition	23.67	-	-	-	-
3-Way Catalyst	136.86	-	-	126.86	-
3-Way plus Ox. Cat.	-	-	-	-	202.96
Exh. Sys. Modifications	-	-	-	1.35	1.35
Feedback Carburetor	32.31	-	-	18.27	18.27
Oxygen Sensor	13.53	-	-	24.85	24.85
T.C.S. System	-	-	-	5.21	5.21
Revised air guard	-	-	-	-	24.85
Delete					
-EGR System	(9.65)	(9.65)	-	(9.65)	(9.65)
-Air Guard System	(39.85)	(39.85)	-	(39.85)	(39.85)
-Underfloor Ox. Cat.	(115.80)	-	-	(115.80)	(115.80)
	41.85	59.76	109.26	11.22	112.17

* Costs represent approximately 17% over dealer costs.
Dollar basis 1977.

Table AMC-18

AMC ESTIMATED FUTURE RETAIL EMISSIONS HARDWARE COSTS*

	1981 vs 1979/80 (First Choice) 0.41 HC, 3.4 CO, 1.0 NOx 4-Cyl (Man & Auto)	 6-Cyl (Man & Auto)
Feedback Carb. (Includes O_2 sensor, etc.)	-	136.32
New 3-Way Cat.	-	202.94
Exh. System Modifications	1.35	1.35
Other Sensors for Micro. Central Digital Microprocessor Control	67.65	7.28
Distributor Revisions for above	43.29	2.71
Improved Air Cleaner and Carb Sealing	20.81	20.81
Programmed Air Injection (use microprocessor and other)	N/A	34.85 74.41
Delete -3-Way Cat.	-	(115.80)
-Microprocessor	-	(67.65)
	133.10	298.02

* Costs represent approximately 17% over dealer costs.
Dollar basis 1977.

1985 vs 1981 0.41 HC, 3.4 CO, 0.4 NOx	6-Cyl (Man & Auto)
Fuel Injection	237.35
Programmed EGR	27.58
	264.93

	Cumulative vs. 1977 Cost* 4-Cyl	 6-Cyl	 8-Cyl
1978	8.54	18.88	22.81
'79/'80	42.39	77.84	131.07
1981	175.40	375.86	N/R
1982	N/R	348.79	N/R

N/R - Not reported

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* Includes evaporative systems costs.

Table AMC-19

AMC Durability Vehicles

Family	CID	System
I-2C	258	EGR+AIR+Start Catalyst+ Oxidation Catalyst

Actual System Miles	HC	CO	NOx	MPG$_U$
4,838	0.40	2.0	1.23	14.0
9,833	0.50	4.2	1.17	14.1
14,838	0.61	3.3	1.36	13.7
19,838	0.63	3.2	1.00	15.1
24,836	0.41	1.6	1.10	14.6
29,813	0.44	3.5	1.06	14.7
29,932	0.42	3.2	1.00	14.6
34,938	0.48	3.1	1.30	14.3
39,918	0.39	3.3	1.22	14.7
44,940	0.44	2.2	1.38	12.2
49,767	0.43	4.1	1.41	13.9
Calc. DF	1.012	1.083	1.200	0.938
Cert. DF	1.012	1.083	1.200	-

Family	CID	System
I-C	232	EGR+AIR+Start Catalyst+ Oxidation Catalyst

Actual System Miles	HC	CO	NOx	MPG$_U$
4,856	0.39	0.7	1.24	14.7
9,835	0.37	1.4	1.11	14.0
14,835	0.45	4.8	1.27	12.7
19,824	0.44	3.8	1.17	12.6
24,853	0.39	0.9	1.15	13.6
29,837	0.43	1.4	1.02	14.1
29,854	0.37	1.1	1.06	14.6
34,827	0.40	1.7	1.15	14.2
39,835	0.37	1.0	1.04	13.4
44,832	0.35	0.9	1.14	13.1
49,901	0.28	0.7	1.01	14.5
Calc. DF	0.791	0.356	0.850	1.003
Cert. DF	1.000	1.000	1.000	-

Family	CID	System
II-C	304	EGR+AIR+2 Start Catalyst+ 2 Oxidation Catalyst

Actual System Miles	HC	CO	NOx	MPG$_U$
4,830	0.32	3.5	1.15	11.7
9,833	0.35	4.8	1.32	11.4
14,831	0.43	5.6	1.48	10.6
19,816	0.67	8.7	1.30	11.5
24,839	0.46	4.2	1.16	11.9
29,833	0.37	3.8	1.21	11.8
29,851	0.41	3.7	1.10	11.5
34,831	0.32	3.3	1.48	11.4
39,833	0.31	4.5	1.57	11.4
44,836	0.39	6.0	1.26	11.2
49,832	0.45	7.3	1.33	11.1
Calc. DF	0.961	1.237	1.085	0.989
Cert. DF	1.000	1.237	1.085	-

Table AMC-20

SOHIO FLEET* - 3-WAY PLUS OXIDATION CATALYST DURABILITY DATA

Veh #	Catalyst Supplier/Canner		Mileage	HC	CO	NOx	MPG
37	Englehard/Walker		41	0.36	5.2	0.61	11.9
			52	0.36	5.1	0.62	12.1
			366	0.30	4.8	0.84	12.6
			8754	0.44	4.5	1.05	----
			16518	0.43	8.1	0.84	13.7
			23902	0.37	3.0	1.08	12.5
			32155	0.45	7.8	1.04	13.5
			39025	0.49	9.1	1.14	13.6
			47649	0.62	11.9	1.24	13.2
		Calc. DF		1.5522	3.2961	1.3461	1.0054
38	Engelhard/Walker		23	0.48	5.0	0.73	11.3
			41	0.42	5.5	0.72	11.8
			353	0.31	4.3	0.92	12.1
			8112	0.40	6.2	0.78	----
			16615	0.41	21.2	0.60	----
			26067	0.49	18.7	0.76	11.5
			32353	0.53	12.4	0.93	12.9
			39092	0.42	7.0	1.15	13.4
			48146	0.52	10.0	0.92	12.9
		Calc. DF		1.3007	0.7175	1.6319	1.2520
62	Engelhard/Maremont		16	0.53	6.8	0.65	11.4
			28	0.45	4.2	0.70	11.9
			44	0.44	5.4	0.64	11.7
			245	0.34	4.0	0.88	12.4
			7711	0.36	8.2	1.04	12.6
			16422	0.52	12.5	0.76	----
			24423	0.42	4.6	0.88	11.8
			31961	0.49	10.9	0.74	12.6
			40245	0.68	11.0	1.02	13.9
			49625	0.42	7.4	0.72	13.0
		Calc. DF		1.3159	0.9529	0.8319	1.0928
63	Engelhard/Maremont		17	0.48	3.4	0.63	11.1
			34	0.33	1.2	0.59	11.5
			45	0.40	3.6	0.78	11.6
			238	0.33	12.5	0.82	11.9
			432	0.30	4.1	0.95	11.8
			8009	0.42	6.9	1.06	----
			16888	0.46	7.4	0.74	----
			23417	0.55	12.2	1.00	13.2
			31711	1.52	26.4	0.90	13.7
			40386	0.39	5.0	1.10	----
		Calc. DF		2.2373	1.9632	1.1431	----

* See Table AMC-6 for more vehicle information.

7.1.1.4. Problems and Progress

Many of AMC's problems appear to hinge on economic considerations. AMC is vendor dependent for components which comprise emission control systems such as catalysts, air pumps, ignition systems, carburetors, and EGR Systems. According to AMC they are limited as to the range of control techniques that can be explored because of the requisite financial commitments that must be made between AMC and vendors.

AMC is also reluctant to investigate the Diesel for its potential in achieving good fuel economy. They claim the uncertainty that exists in regard to future NOx standards and the lack of demonstrated ability of existing Diesel designs to meet stringent future NOx standards precludes their investment of the capital required to design, develop, and tool a Diesel engine for production. AMC did not indicate whether or not the 4-cylinder engine they are currently using (which is adapted from a VW/Audi design) would be capable of being Dieselized in the same manner as the VW engine.

Related to engine and system development, AMC does not have the instrumentation to measure such dynamic aspects as engine exhaust flow rate, air flow rate, EGR flow, and air injection flow as a function of time during the Federal Test Procedure. They also do not have computer controlled test equipment for conducting engine dynamometer and chassis dynamometer multi-parameter optimizing programs. They do, however, anticipate expanding their work in such optimization programs. This work must be accomplished soon if AMC is to provide programmed control of fuel metering, ignition timing, EGR, and air injection to meet emission levels of 0.41 HC, 3.4 CO, 1.0 NOx and lower.

AMC is concerned with proposed and anticipated changes to EPA test procedures for 1979, presumably the 2 gram evaporative standard, increasing the light duty truck coverage to include up to 8500 lbs GVW, and fuel economy regulation changes in road load determination, inertia weight increments, fuel specifications, and using actual distance traveled. They claim some of the test procedure changes will result in an increase in stringency of both the emission standards and fuel economy requirements while creating confusion and doubt in their currently scheduled programs and plans. AMC also estimates these procedural changes will mean an 8% loss in fuel economy with an equal emissions penalty for their 1979 model year vehicles.

If the Federal protocols (i.e. no line crossing) were used in analysing their 1977 California durability vehicle data, all of AMC's durability vehicles would not have met the 0.41 HC, 9 CO, 1.5 NOx standards. AMC contends that there is insufficient lead time to redesign or recalibrate their California systems and run the required 50,000 mile durability distance to release these systems for 1978 49-state production.

If 1977 emission standards are carried over to 1978, AMC expects to maintain an approximate fleet fuel economy of 19.2 MPG_c compared to the legislated requirement of 18 MPG_c. AMC's development efforts targeted for 1979+ are directed toward vehicles with 4 and 6-cylinder engines. AMC estimates that these engines will represent the largest part of their sales volume for this period and thus will have a major impact on their ability to meet future fuel economy requirements.

7.1.2. Chrysler

7.1.2.1. Systems Under Development

Oxidation Catalyst Systems

Chrysler's oxidation catalyst system work over the past year has been fairly limited. The following areas have received some attention:

1. Improved oxidation catalysts.
2. Air switching during closed throttle.
3. Modulated air injection.

Chrysler reported a limited amount of work aimed at upgrading conventional oxidation catalysts. This was confined for the most part to evaluating vendor samples with new arrangements of noble metal and substrate. Chrysler reported that none of these evidenced improved activity as compared to 1977 production models. Of interest was a British catalyst which featured a metallic honeycomb substrate. This catalyst showed high activity at very low inlet oxygen levels but its activity dropped off sharply at higher oxygen levels.

Chrysler has evaluated samples of precious metal, perovskite oxidation catalysts supplied to them by DuPont. Perovskite catalysts bind up the catalytically active metal in a perovskite crystal lattice. Test evidence has indicated that this provides some degree of protection against lead poisoning. Chrysler's evaluation procedure involved a dynamometer procedure which simulated 100 hours of operation on fuel containing 1.5 gm/gal lead. Chrysler reported that although HC activity for the complete catalyst was not diminished, a more detailed investigation showed that the front edge of the catalyst had lost much of its activity. This implies that as with conventional catalysts, the lead poisoning proceeds from the front edge on toward the rear of the catalyst, but how long this takes and how much of the activity is lost in the interim is unclear. Chrysler performed single cylinder studies to determine the effect of single cylinder studies to determine the effect of temperature on the HC and CO conversion efficiency of perovskite catalysts using leaded fuel. This study indicated that at high temperature (1200°F) a 3 1/2 hour exposure to leaded fuel showed little effect upon CO conversion efficiency but caused a 50% drop in HC conversion efficiency. The HC conversion efficiency remained constant, but the CO conversion efficiency dropped for low temperature (800°F) exposure. The HC conversion efficiencies for these perovskite catalysts were substantially lower than the HC conversion efficiencies of conventional oxidation catalysts.

Chrysler reported on their evaluation of an air switching system that provides air to the exhaust manifolds during closed throttle modes. These modes produce relatively cool, HC rich, exhaust; thus manifold air injection should improve conversion efficiency. However, to prolong the life of the start catalyst in this system, it is necessary to switch air downstream during normal warmed-up operation. Chrysler evaluated this system by comparing emission results to emission results with the coolant controlled air switching system. The closed throttle switching system also contained the coolant controlled switching feature. The coolant controlled system is standard equipment on 1977 California models. It diverts air from the exhaust manifold to a position downstream of the start catalyst after the coolant temperature reaches 98° F. Table Chrysler-1 shows the test results of the two systems. Chrysler indicated that the closed throttle air injection system would not be pursued further because the HC benefit did not warrant the increased cost and complexity.

Table Chrysler-1

Closed Throttle Air Switching
4000 IW, 225 cu in., Start Catalyst Plus Main Catalyst

System	HC	CO	NOx	Fuel Economy-MPG$_U$
Air switched upstream on closed throttles (4 run avg.)	0.683	4.53	0.618	14.66
Air switched upstream for coolant below 98°F (3 run avg.)	0.745	4.39	0.559	14.68

Following up on earlier dynamometer work which showed that a significant improvement in HC conversion efficiency resulted from a decrease in excess secondary air injection, Chrysler outfitted a vehicle with an air modulation system. The modulating valve was a Dodge Colt air switching valve which Chrysler had modified to provide about 2.5% excess air. Test results for this system are shown in Table Chrysler-2. These results show degraded HC and CO emission control for the modulated system. These results did not confirm the trend indicated by the dynamometer results. It is not known how well the air control system performed in providing the desired amount of injected air as a function of speed and load. Considering the sulfuric acid emission benefits (and potential gaseous emission benefits) of truly optimized air injection systems it appears that optimized air injection systems, possibly more sophisticated than the one investigated by Chrysler, may require further development work.

Table Chrysler-2

Modulated Air Testing
1975 Dart, 225 cu in., Oxidation and Reduction Catalysts

System	HC	CO	NOx
Full Air (2 test avg.)	0.10	0.36	0.98
Modulated Air (2 test avg.)	0.13	1.65	1.00

3-Way Catalyst Systems

Chrysler has assembled and tested both single and dual bed 3-way catalyst systems. These systems are called a 3-way catalyst system, and a 3-way plus oxidation catalyst (3-way + OC) system.

Chrysler believes that the most promising formulations for 3-way catalysts are platinum/rhodium and perovskite stabilized ruthenium plus platinum. Their evaluation procedure consists of laboratory testing, dynamometer testing, vehicle screening testing, and durability testing.

These different phases tend to be sequential, i.e., a catalyst formulation will progress from one test phase to the next if results continue to indicate good potential. Unfortunately, Chrysler's vehicle test work, both durability and screening, may have been hampered by the use of open loop air-fuel metering. They have identified Electronic Fuel Metering (EFM) as an essential constituent of their future 3-way catalyst systems. The need for EFM or an alternative advanced fuel metering system is related to the conversion characteristics of 3-way catalysts. These dictate that the air-fuel ratio must be held fairly precisely at stoichiometric in order to maintain good conversion efficiency for all three pollutants. Chrysler's catalyst development efforts have for the most part been done with conventional carburetors operating open loop, i.e., no feedback. This may have made it difficult for Chrysler to accurately assess the capabilities of the catalyst formulations under consideration.

The majority of the platinum/rhodium catalysts evaluated have had Pt/Rh ratios in the area of 5/1. Catalyst volumes have been small (20 to 30 cu in. is typical) which is possibly the result of space limitations.

Most of Chrysler's screening tests for conventional 3-way catalyst systems were conducted on five cars. These cars represented a fairly broad range of engines and inertia weights. All employed conventional carburetors. Table Chrysler-3 shows the best emission results achieved along with brief vehicle and catalyst descriptions.

Table Chrysler-3

3-Way Catalyst Screening
Conventionally Carbureted Systems

Model	CID	Catalyst	HC	CO	NOx	MPG_U	1977** MPG_U
Valiant	225	Chrysler 5/1*	0.32	2.4	0.71	16.6	16.7
Duster	225	Engelhard 5/1	0.31	2.6	0.77	19.1	16.7
VW Rabbit	97	Unspecified	0.37	8.8	0.52	25.4	24.9
Volare	225	Unspecified	0.59	7.9	3.61	16.5	16.7
Fury	318	Chrysler 5/1	1.09	10.3	0.95	13.6	13.6

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* Ratio of platinum to rhodium
** Fuel economy of 1977 Certification durability car.

Chrysler reported one vehicle evaluation of a Pt/Rh catalyst on a system that included closed loop carburetion. This involved two 30 cu in. catalysts installed on a Plymouth Fury equipped with a 360 CID engine and a Holley closed loop feedback carburetor. One 1975 FTP test was reported with the following emission results: 0.367 HC, 8.96 CO and 1.64 NOx.

Chrysler has done a limited amount of 3-way catalyst screening using a 360 CID Plymouth equipped with Bendix Electronic Fuel Injection (EFI). This system included EGR, closed loop oxygen sensor control with adjustable features, and secondary air during warmup. The system was used to evaluate two types of perovskite 3-way catalysts. The first type was composed of two biscuits. One biscuit was a perovskite material supplied by DuPont and the other was of unspecified content supplied by UOP. Chrysler tried several air-fuel ratio and EGR settings and also reversed the order of the biscuits. The best emissions from this system were 0.32 HC, 4.81 CO and 0.65 NOx.

3-Way Plus Oxidation Catalyst Systems

Chrysler has identified 3-way plus oxidation catalyst (3-way + OC) systems as their first choice approach to meet the 0.41 HC, 3.4 CO, 1.0 NOx and 0.41 HC, 3.4 CO, 0.4 NOx levels. The appeal of the 3-way + OC system is due in a large part to the improved control of HC and CO derived from the extra "clean up" oxidation catalyst. This can also give NOx control benefits by allowing the system to be biased slightly rich of stoichiometric, thereby increasing the NOx control. The HC and CO control suffer when this is done but the increased HC and CO may be able to be handled in the oxidation catalyst. An important drawback to 3-way + OC is that the sulfuric acid emissions are likely to be higher than with a 3-way catalyst system alone. Another disadvantage is that any ammonia generated in the 3-way catalyst is converted to NOx in the oxidation catalyst, thus decreasing the net system NOx conversion.

As with their single bed 3-way catalyst development work, Chrysler may have been handicapped in their evaluation of 3-way + OC catalyst performance by a lack of suitable advanced fuel metering systems. Further constraining their performance were the packaging limitations present in current body structures. Thus catalyst sizes were fairly small with 22 cu in. being the most common size. Chrysler's evaluation efforts have been directed primarily toward platinum/rhodium and perovskite stabilized ruthenium plus platinum formulations. The use of the term "stabilized" to describe Chrysler's ruthenium-containing catalyst is Chrysler's. Tests run to measure ruthenium loss (see Section 6) have shown that the stabilization may not be effective. Chrysler reported low mileage catalyst screening testing on twelve vehicles. Table Chrysler-4 shows some of the better emission results for this testing along with brief system descriptions.

Table Chrysler-4

3-Way + Oxidation Catalyst Screening
Conventional Carburetor Systems

Model	CID	Catalyst	HC	CO	NOx	MPG_U	1977* MPG_U
Valiant	318	Chrysler Pt/Rh	0.30	3.35	0.63	11.7	-
Fury	318	Chrysler Pt/Rh	0.26	3.6	0.56	11.9	13.6
Dart	360	Chrysler Pt/Rh	0.35	3.5	0.73	11.1	-
Duster	225	Chrysler Pt/Rh	0.49	2.2	0.34	17.9	16.7

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* Fuel economy of 1977 Certification durability car.

Chrysler reported test results for a 3-way + OC system on the Holley closed loop carburetor equipped Fury described earlier. Table Chrysler-5 shows emission results for a Chrysler perovskite 3-way + OC system on this car. Also shown are results of this same 3-way + OC system but with an open loop four barrel carburetor.

Table Chrysler-5

3-Way Catalyst System Results
500 IW Fury 360 CID V-8

System	HC	CO	NOx	MPG_U
3-way cat.* closed loop	0.367	8.96	1.64	-
3-way** + OC closed loop, EGR	0.24	1.65	0.81	11.6
3-way** + OC closed loop, no EGR	0.17	3.51	0.96	10.4
	0.19	1.67	0.78	10.6
	0.22	1.85	0.73	11.6
	0.21	1.75	0.87	11.6
3-way** + OC open loop, EGR	0.33	2.44	0.83	11.5

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* Pt/Rh
** Perovskite

Dual Catalyst Systems

In last year's submission Chrysler reported some promising results from their base metal NOx catalyst development program. Chrysler's latest system at that time included their M 23AC' base metal catalyst along with air switching and heat conservation techniques, i.e., exhaust port liners and an insulated exhaust system. At the time of the last report, a car with this system had accumulated 20,000 miles of durability while remaining well below statutory emission levels. Chrysler provided an update on this car in this year's report.

Some degradation of emission control occurred between 20,000 and 28,000 miles. At 20,000 miles the emissions were 0.32 HC, 2.50 CO, 0.36 NOx. At 28,000 miles the emissions were 0.40 HC, 5.73 CO, 0.49 NOx (5 test average). At 28,000 miles an involved series of carburetor adjustments were made. Chrysler then discovered changes in the pressure drop across the catalysts. Investigating this, they found that all of the catalyst material was missing from one container and part of the material was missing from the other. There is some uncertainty about the role played in this failure by the extensive carburetor calibration work.

Chrysler has been working on alternative base metal formulations and substrate types. These include higher chromium alloy formulations and ceramic substrates. Chrysler installed one of the higher chromium alloy catalysts on one side of the vehicle used for the previously described test. The other side contained the original formulation. After 30,000 miles Chrysler reported that both catalysts showed significant material loss but the high chromium alloy had fared better. The ceramic substrate catalyst and an International Nickel Company catalyst (INCO 1013) have shown favorable dynamometer test performance and Chrysler intends to start vehicle testing soon. Some interesting data were presented showing the effects of heat conservation techniques on dual catalyst systems using base metal NOx catalysts. Table Chrysler- 6 shows this data for a system identical to the original test vehicle for the MR 23AC' catalyst.

Table Chrysler-6

Effect of Heat Conservation Techniques
1976 Plymouth Fury, 360 CID, Dual Catalyst

System	HC	CO	NOx	MPG_U
Production manifolds, no port liners	0.45	4.04	0.64	11.37
Insulated manifolds, port liners	0.34	2.93	0.34	11.18
Indicated improvement	24%	27%	47%	-2%

In their previous status report Chrysler reported the accumulation of 15,000 miles of durability on a Gould GEM 68 dual catalyst system. At this point, Chrysler noted a substantial increase in pressure drop across the NOx catalysts and suspended testing. Subsequent study by Gould of the durability characteristics of GEM 68 has revealed an intolerance to fuel containing fuel sulfur levels representative of typical pump fuel. This intolerance results in depletion of the catalyst and an increase in pressure drop across the catalyst. The Chrysler experience appears to fit this pattern.

Other Development Efforts

Chrysler is evaluating several advanced fuel metering systems for possible future useage in oxidation catalyst, 3-way catalyst, and dual catalyst systems. These systems are Bendix Electronic Fuel Injection (EFI), the Holley Closed Loop Carburetor, the Carter TQ carburetor, and two Chrysler-developed, closed loop carburetors.

Chrysler's testing of the Bendix EFI system has shown that when operating open loop the system produces less than half the air-fuel ratio fluctuations normally experienced with carburetion. This system is currently being evaluated on a 3-way catalyst equipped 1975 Plymouth with a 360 CID engine. The most recent emission testing of this system showed 0.32 HC, 4.81 CO, 0.65 NOx and 11.08 MPG_U. The urban fuel economy of this same model in 1977 durability testing was 11.94 MPG.

The Holley closed loop carburetor has undergone preliminary evaluation testing by Chrysler with initially favorable results. Chrysler reports that this closed loop fuel metering control system shows only about one fourth of the variation normally seen with carburetors. Emission results for this carburetor on a 3-way catalyst system were shown in Table Chrysler-5.

Both the Carter TQ carburetor and Chrysler's in-house developed carburetors are closed loop feedback systems which employ linear solenoids to move control needles in the air bleeds of the main and idle circuits. The details provided were quite sketchy but the TQ carburetor is assumed to be a two barrel or four barrel unit since it has been installed on a V-8 engine. One of the Chrysler carburetors is a modified Holley model 1945. This model is a one barrel unit used on the 225 CID six cylinder engine. Both the Chrysler and Carter systems have recently been installed in vehicles equipped with 3-way catalysts. No emission data were reported.

Chrysler is working on a second closed loop carburetor of their own which is a four barrel unit and reportedly includes several interesting features. These include electronic compensation for sensor aging, open loop operation during warm-up, and monitoring features to detect incipient and actual failures. The compensation feature for sensor aging was originally intended to make use of the small alternating current "ripple" component produced by the sensor when the air-fuel mixture is at the stoichiometric point. The circuitry would evidently have keyed upon this and automatically adjusted for drift due to aging. Chrysler reported that problems were experienced with the circuitry which resulted in inadequate response. They are now pursuing an alternate approach to achieve sensor aging compensation. The system for detecting sensor deterioration and failure monitors the electrical resistance of the sensor. This resistance increases significantly as it deteriorates. This increase is detected and the circuitry is programmed to revert to open loop operation. This feature could be used to alert the operator to the need for sensor replacement. No dynamometer or vehicle emission data were provided for this carburetor.

Chrysler is also developing their own Electronic Fuel Metering (EFM) system. This system features a proprietary air flow measurement technique and a single point fuel injection system. It will sense important operating parameters such as coolant temperature, atmospheric pressure and ambient temperature and tailor the fuel metering to accurately compensate for changing conditions. Air-fuel ratio fluctuations and cylinder-to-cylinder variation will reportedly be reduced by improved transient response characteristics and better air-fuel mixing. One version of the system will include closed loop oxygen sensor feedback control. The electronic control unit is currently an analog unit but eventually will become digital for improved control capability and compatibility with Electronic Spark Advance (ESA) which is also being converted to a digital system. Chrysler appears to be putting a significant portion of its research and development resources into EFM and is relying on it to play a central role in future systems. Chrysler has three potential modes of operation in mind. These are:

1. very lean (target is vicinity of 20:1)
2. stoichiometric, open loop
3. stoichiometric, oxygen sensor feedback

Some of the better low mileage test results from vehicles equipped with EFM, ESA, and oxidation catalysts can be found in the following Table. No air injection or EGR were used on the test vehicles.

Table Chrysler-7

Low Mileage EPA Results*

Car	HC	CO	NOx	MPG_U	MPG_H
#293	0.364	1.77	1.53	9.4	17.8
	0.329	2.38	1.62	11.0	19.9
	0.324	2.76	1.82	9.7	19.0
	0.231	1.35	2.07	8.7	18.9
	0.194	1.36	2.00	9.2	18.9
	0.335	2.53	1.56	8.0	-
#294	0.268	2.26	1.44	10.1	17.8
	0.276	3.31	1.55	10.5	19.1
	0.350	2.87	1.53	11.8	19.7
	0.345	2.06	1.17	11.9	19.8
	0.409	1.30	1.22	11.9	19.4
	0.403	2.03	1.34	12.9	19.9
#529	0.286	1.77	1.60	9.9	18.8
#639	0.322	1.60	1.43	11.2	19.3

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* All vehicles were equipped with 360 CID engines and automatic transmissions.

Chrysler reported that comparative durability testing is in progress on oxygen sensors from three manufacturers. These are Bosch, UOP and Nippondenso. To date, the durability performance of the three is approximately equivalent and ranges from about 10,000 to 38,000 miles. The main cause of failure is reportedly water splash which occurs when the cars are driven through a water splash trough. Chrysler is working on a splash protection system which should be a straightforward type of problem to solve.

Chrysler reported evaluation work on an electrically heated vaporizer tube which is situated in the carburetor above the throttle blade. This device is intended to permit leaner mixtures for cold start and warm-up than a conventional choke. Chrysler reported that they were unable to achieve the degree of precision in vaporization control that they deemed necessary. As a result, Chrysler has suspended work on this item.

Some of the better reported results from two vehicles equipped with the vaporizer are shown in Table Chrysler-8. Car 216 had a lean calibration, and did not use a catalyst, air injection, or EGR. Car 633 was equipped with a base metal NOx catalyst, an oxidation catalyst, air injection and EGR. Both vehicles used 318 CID engines and were tested at 4500 IW.

Table Chrysler-8

Low Mileage Vaporizer Testing

Car	HC	CO	NOx	MPG_u	MPG_h
#216	1.19	6.07	1.96	11.4	-
#216	1.21	6.14	2.28	11.7	-
#216	1.25	5.68	2.07	12.0	-
#633*	0.42	2.84	0.33	13.3	15.8
#633*	0.47	3.18	0.43	11.1	-
#633*	0.40	3.50	0.38	12.2	18.5
#633	0.49	1.26	0.40	11.4	17.7
#633	0.45	3.37	0.44	11.6	18.3
#633	0.39	2.46	0.52	11.5	-

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* without vaporizer

Chrysler reported development work on turbulent flow (TF) intake manifold systems for the 225 CID six cylinder engine and a V-8 (displacement unspecified). Chrysler's units are variations of the Ethyl system and include a provision for admitting EGR through an annular plate at the base of the carburetor. No emission results were presented but Table Chrysler-9 presents data showing substantial improvements in cylinder-to-cylinder distribution of EGR and fuel-air mixture.

Table Chrysler-9

Turbulent Flow Manifold System

Manifold	EGR Variation	Fuel-Air Variation
Production 1-bbl.	5.7 to 16.7%	2.1 to 7.2%
TF 1-bbl	2.2 to 7.3%	1.7 to 3.0%
Production 2-bbl	11.2 to 24.4%	3.6 to 7.7%
TF 2-bbl	2.3 to 8.1%	1.6 to 3.6%

Chrysler is performing engine studies to determine the optimum scheduling of their electronic fuel metering (EFM), electronic spark advance (ESA), and electronic EGR (EEGR). Ultimately, these systems will be controlled through a central microprocessor which will be programmed to provide optimum scheduling of fuel-air ratio, spark advance and EGR. Chrysler is currently working on a computer model to select the optimum schedules. Although Chrysler's current ESA and EFM systems are analog units, they intend to switch over to digital units as soon as practicable. This should provide improved control and programming capability.

Chrysler reports progress on their electronically controlled EGR (EEGR) system. Problems were experienced in the following areas: debugging the electronics, achieving sufficient flow rates, and getting adequate flow during acceleration modes without getting excessive rates during cruise modes. As a result of these difficulties Chrysler has decided to wait until their central electronic control unit is available before introducing EEGR. Theoretically this central unit will have a greatly improved ability to specify the optimum amount of EGR.

Chrysler reported development studies on cooled EGR. The principal benefits here would be a decrease in maximum combustion temperature, decreased octane requirement, and increased EGR flow rate through a given orifice (minor benefit). Chrysler is using two schemes to accomplish the cooling; water and air. The air cooling arrangement appears to be the most effective in terms of temperature drop of the EGR. However, vehicle test data were inconclusive. Two vehicles were equipped with the air cooled systems and one car with the water cooled. One of the air cooled vehicles showed a reduction in NOx but the other two vehicles showed increases.

Chrysler has evaluated the effectiveness of slowing the warm-up of engine coolant and reducing the coolant temperature as a means of reducing NOx. This is accomplished by bypassing the thermostat and routing the coolant directly to the radiator. A temperature actuated switching mechanism does this at warm ambient temperatures only, due to the driveability problems that would occur at cold temperatures. It is presumed that the bypass flow would be operative primarily during the emission test conditions. As shown in Table Chrysler-10 the test data showed some reduction in NOx emissions but at a concurrent penalty in HC emissions and fuel economy. Chrysler has specified this system for future systems meeting stricter emission levels. They also refer to this system as the dual range thermostat.

Table Chrysler-10

Thermostat Bypass System
1975 Dodge, 360 CID, 5000 IW

	HC	CO	NOx	MPG_u	MPG_h
Baseline	0.16	3.1	1.41	10.5	19.0
Bypass	0.19	2.4	1.23	10.3	18.8

Chrysler reported continued work on ceramic coated combustion chambers. The objective is to insulate the chamber, thereby creating higher surface temperatures which should decrease HC emissions. To date Chrysler's work has been limited to single cylinder engine testing, but results have been promising (lower HC and decreased deposits). The big question marks are octane requirements and durability. Chrysler will reportedly equip a six cylinder engine with the ceramic coated combustion chamber to evaluate these factors. It has taken a long time for this project to move from the single-cylinder phase of testing to the multi-cylinder engine dynamometer phase.

Having established the emission control and fuel economy benefits of exhaust port liners, Chrysler is studying the feasibility of making them an integral part of the head casting. This new configuration has been designed and will soon be tried out in production core boxes.

Chrysler is evaluating two systems intended to improve highway fuel economy by selectively switching out engine cylinders. No technical details or data were provided but the systems were identified as the "Dolza" and "Eaton Valve Selector" systems. The systems will be evaluated for their effect upon emissions, fuel economy and driveability.

Chrysler is undertaking two Diesel engine development and evaluation programs. The first is aimed at adapting an open chamber Diesel to automotive use. Open chamber Diesels are generally harsher, noisier, harder starting, and produce more NOx emissions than pre-chamber engines. However, open chamber engines have the advantage of lower heat transfer and reduced flow losses and, thus have potentially better fuel economy. To overcome the cited drawbacks, Chrysler is working with Eaton on a concept called staged injection. Chrysler did not provide any technical details or test data but they did express confidence that this concept will result in peak pressures that are low enough to permit the use of gasoline engine structures and materials. Chrysler also indicates that NOx levels below 1 gm/mi are attainable while still maintaining a significant fuel economy advantage over conventional gasoline engines. Chrysler reported that these promising expectations are based upon initial single cylinder test results. A multi-cylinder version is now undergoing testing, and procurement is reportedly underway for a 225 CID production engine equipped with this approach.

Chrysler is also pursuing the more conventional approach to Dieselizing a gasoline engine, i.e., pre-chamber heads and a more conventional injection pump. Ricardo and Company Engineers Ltd. of England is under contract to Chrysler to convert a six cylinder gasoline engine. The Ricardo Comet Mark V indirect injection combustion chamber will be used along with a Roosa Master injection system. Dynamometer testing is now underway and a vehicle installation is slated for early 1977.

Chrysler presented some interesting test data showing the effect of EGR and injection retard on the NOx and fuel economy of a Nissan Diesel. Table Chrysler-11 is extracted directly from their submission.

Table Chrysler-11

Effect of EGR and Injection Retard
on a Nissan Diesel

EGR	Timing	NOx	Fuel Economy
No	Standard	----------Baseline----------	
No	5° Retard	Down 21%	Down .8%
No	10° Retard	Down 37%	Down 8.1%
8%	Standard	Down 32%	0
8%	5° Retard	Down 53%	Down 5.7%
16%	5° Advance	Down 32%	Down .4%
16%	Standard	Down 63%	Down 3.6%
16%	5° Retard	Down 63%	Down 1.6%

Table Chrysler-12 shows the fuel economy and emissions of the vehicle with different timing/EGR calibrations. HC and CO tended to increase as NOx was reduced. The hydrocarbon performance for this vehicle was worse at all conditions than many other Diesel vehicles tested by EPA. At the lowest NOx level, (0.7 NOx) the fuel economy was less than 2% lower than the baseline (1.9 NOx) case, although CO was 5.0 gm/mi and HC was not reported.

Table Chrysler-12

Effect of EGR and Injection Timing

Car 439 - Nissan Diesel

EGR	Injection Timing	CVS Emissions, gm/mi			Fuel Economy, MPG		
		HC	CO	NOx	Urban	Hwy	Comp
No	Standard (Base)	1.0	1.7	1.9	22.0	29.0	24.7
No	5° Retard	1.3	1.7	1.5	22.0	28.4	24.5
No	10° Retard	3.4	3.0	1.2	20.4	26.2	22.7
8%	Standard	1.7	2.7	1.3	21.8	29.4	24.7
8%	5° Retard	1.9	3.1	0.9	21.1	26.7	23.3
16%	5° Advance	1.8	4.1	1.3	21.9	27.3	24.6
16%	Standard (3)	2.2	4.4	0.7	21.2	26.4	23.8
16%	5° Retard	-	5.0	0.7	22.2	26.4	24.3
1977 Plymouth Volare (3500 IW)		1.0	10	2.0	20	29	23
1977 Dodge Aspen* (4000 IW)		1.0	15	2.0	17	24	20

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* 1977 Certification results; best fuel economy of comparable vehicles. (IW not specified for Diesel Dart)

While Chrysler's ERDA-supported efforts on the automotive gas turbine program are continuing, they estimate that the anticipated performance of the engine under development will fall substantially short of the 1985 fuel economy requirements. Chrysler believes that ceramic materials are a must for the hot rotating components if a gas turbine is to be competitive with current engines on a fuel economy and initial cost basis. Chrysler feels that the necessary materials technology will not be available until the post-1985 time-frame.

Chrysler reported some interest in the Mitsubishi MCA-JET system (see the section on Mitsubishi). Chrysler is now designing an experimental version of their 225 CID six cylinder engine with this system incorporated. The MCA-JET system reportedly allows the attainment of the theoretical emissions and fuel economy advantages of super lean mixtures without the combustion and driveability problems normally experienced.

Chrysler's fuel economy improvement programs emphasize engine and body weight reduction along with smaller displacement engines. Chrysler projects a 700 to 900 lb drop in its fleet average inertia weight by 1985. The details of how this will be done were not provided, but Chrysler appears to be stressing the use of lighter weight materials such as plastics and aluminum. Engine weight reduction will be accomplished by trimming weight from the cylinder block, heads, and many internal parts. Downsizing will also be employed, but it appears that this may not be used to as great an extent as early as forecast by some other domestic manufacturers. Chrysler is also studying the benefits and drawbacks of more efficient transmissions. This work has shown a 3% improvement in urban fuel economy and a 6% improvement in highway fuel economy with a low stall speed, lockup torque converter. The major drawbacks to this type transmission are increased complexity, abrupt shifts and the possibility of degraded durability, according to Chrysler.

7.1.2.2. Systems to Meet Various Emission Levels

Table Chrysler-13 shows Chrysler's first choice systems to meet various emission levels. The fuel economy and system cost estimates are from Chrysler.

7.1.2.3. Durability Testing

Chrysler's durability testing over the past year has been aimed largely at evaluating the durability of various 3-way catalyst formulations. Table Chrysler-14 summarizes the reported testing. As previously discussed, Chrysler intends to use an advanced fuel metering system, such as their EFM, on 3-way catalyst systems. This is in agreement with the latest technical knowledge which indicates that relatively precise air-fuel ratio control is essential. Unfortunately, it appears that Chrysler has not run many vehicles equipped with this fuel metering system and advanced 3-way catalyst systems in combination. Consequently, they have been forced to conduct catalyst durability evaluations with fuel metering systems that may not effectively simulate the catalyst performance that would result from their planned future systems. How Chrysler interprets the results of the testing with these incomplete systems, and how Chrysler uses the results to predict what the emission performance of full systems would be, was not reported by Chrysler.

If one considers the results shown on Table Chrysler-14 in light of the improvements shown on Table Chrysler-5 that would correspond to the application of feedback carburetion, then an estimate of performance of the vehicles, if equipped with a feedback carburetor, can be made.

The results appear to indicate that these vehicles could be expected to meet 0.41 HC, (especially if a methane credit is assumed), to be close to, but not far enough below 3.4 CO to have much confidence in predicting compliance, and to be able to meet 1.5 NOx. It should be noted that many of the vehicles did not use EGR.

Table Chrysler-5

First Choice Systems To Meet
Various Emission Standards
- Typical V-8 Engine (318) -

Hardware	1977 (A) 1.5, 15, 2.0 (Base)	(B) 0.41, 3.4, 2.0	(C) 0.41, 3.4, 2.0	(D) 0.41, 3.4, 1.0	(E) 0.41, 3.4, 1.0
Electronic Spark Advance	-	X	X	X	X
Orifice Spark Advance	X	-	-	-	-
Altitude Compensation	-	X	X	X	-
Electronic Fuel Metering	-	-	X	-	X
Fresh Air System	X	X	X	X	X
Heated Air System	X	X	X	X	X
Air Pump	-	X	X	X	X
Air Switching	-	X	X	X	X
Aspirator	X	-	-	-	-
Coolant Controlled EGR	X	X	X	X	X
EGR Timer	-	X	X	X	X
Main Catalyst	90 cu in. (50-0)	152 cu in. (100-0)	152 cu in. (100-0)	152 cu in. (100-0)	152 cu in. (100-0)
Single Start Catalyst	-	22 cu in. (200-0)	-	-	-
Dual Start Catalyst	-	-	-	45 cu in. (100-0)	-
Dual Three-Way Catalyst	-	-	45 cu in. (10-1)	-	45 cu in. (10-1)
Oxygen Sensor	-	-	-	-	X
Power Heat Valve	-	X	-	-	-
Dual Range Thermostat	-	X	X	X	X
Idle Enrichment	X	-	-	-	-
Constant Idle Speed (AIS)	-	-	X	-	X
Solenoid Idle Stop	-	X	-	X	-
Vapor Separator	-	X	X	X	X

Table Chrysler-13 (continued)

Hardware	1977 (A) 1.5, 15, 2.0	(B) 0.41, 3.4 2.0	(C) 0.41, 3.4, 2.0	(B) 0.41, 3.4, 1.0	(C) 0.41, 3.4, 1.0
Increased Thermal Protection (Heat Shields, etc.)	-	X	X	X	X
Radiator Fan Speed & Blade Revisions	-	X	X	X	X
Increased Radiator Fluid Capacity	-	X	X	X	X
Oxygen Sensor Maintenance Warning Light	-	-	-	-	X
Fuel Economy *	Base	-6%	Not Provided	-12%	Not Provided
System Cost	Base	+$255	+$315	+$315	+$350

(A) Main Catalyst Only (1977 Federal)
(B) Start + Main Catalyst
(C) 3-Way + Main Oxidation Catalyst

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* Relative to 1977 49 state standards; Chrysler estimate

Table Chrysler-1A

Durability Test Results

Model	IW	Engine	System Catalyst	Fuel Metering	Accumulated Mileage	Emissions Start/Finish HC	CO	NOx	MPG$_U$	'77 Model** MPG$_U$
A-Body	4000	225 six	3-way + OX* Pt/Rh + Pt	Carburetor open loop	0 50K	0.36 0.52	1.78 3.16	1.46 1.31	13.55 14.51	16.7 16.6
A-Body	4000	225 six	3-way + OC perovskite/Pt + Pt	carburetor open loop	0 25K	0.58 0.52	4.08 4.72	0.77 1.06	16.2 17.2	16.7 16.6
A-Body	4000	225 six	3-way + OC perovskite/Pt + Pt	carburetor open loop	0 50K	0.48 0.67	7.26 11.5	0.77 1.12	12.79 14.26	16.7 16.6
A-Body	4000	225 six	3-way + OC Pt/Rh + Pt	carburetor open loop	0 50K	0.36 0.52	3.6 3.7	0.99 1.05	17.0 16.6	16.7 16.6
F-Body	4500	318 V-8	3-way + OC Pt/Rh + Pt	carburetor open loop	0 50K	0.27 0.66	3.1 7.9	0.74 1.17	11.9 12.9	12.9 12.7
B-Body	5000	360 V-8	3-way + OC Pt/Rh + Pt	carburetor open loop	0 50K	0.47 0.36	3.8 2.2	0.61 1.56	10.3 11.7	11.9 12.5
C-Body	5000	360 V-8	3-way + OC Pt/Rh + Pt	carburetor open loop	0 50K	0.28 0.39	3.6 4.7	0.52 1.39	11.9 11.8	10.5 9.6
C-Body	5000	360 V-8	3-way + OC Pt/Rh + Pt	carburetor open loop	0 50K	0.56 0.52	2.5 4.4	0.77 1.27	11.4 11.6	11.9 12.5

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* 3-way + Oxidation Catalyst

** Fuel economy of 1977 Certification durability car; 0 mile figure is actually 5K value

7.1.2.4. Progress and Problems

The discovery of the attrition problem with the base metal NOx catalyst casts serious doubts on this once promising approach.

On the positive side, Chrysler is enthusiastically pursuing their EFM system. This system, if successful, could open up several attractive options, such as extremely lean or 3-way catalyst system operation.

Little progress has been made in their ceramic combustion chamber work. This concept had shown significant potential for reductions in HC emissions. Progress over the past year has been limited to the coating of a six cylinder engine for which no test data have yet been reported.

It is difficult to assess Chrysler's ability to comply with 1.0 or 0.4 NOx requirements because they have not tested any systems that bring together all of their planned hardware. An example of this is their 3-way catalyst screening and durability testing. The results shown here were higher than the target standards in many instances, but it is difficult to determine how much of this is attributable to the catalyst and how much is attributable to the fuel metering.

Current emission control systems have been compromised in some instances by packaging limitations of existing chassis/body designs. This is especially true for catalysts that should be located as close to the exhaust manifold as possible. Current body structures frequently prevent the installation of a properly sized unit due to insufficient space. For example, this may force the designer to get along with a 30 cu in. catalyst instead of the 60 cu in. unit he really needs. The difference in size between the two, in some cases, is only an inch or two at the critical clearance dimension. When new, redesigned, body structures are contemplated for revised vehicles, it has been assumed that provisions would be made for future emission control items.

However, in discussions with Chrysler, EPA learned that some future vehicle bodies may not fully take these emission control system needs into account. Apparently, it is a matter of priorities, and emission control may not be high enough on the list.

7.1.3. Ford

7.1.3.1. Systems Under Development

3-Way Catalysts

Ford has conducted a considerable amount of laboratory testing of 3-way catalysts. Primary efforts have been in the areas of: 1) effects of noble metal loading, 2) effects of rodium (Rh) concent, 3) the addition of active materials to enhance the steam reforming for HC control, 4) the addition of active materials to enhance the water gas shift reaction for CO control, 5) the addition of active materials to enhance oxygen storage in the catalyst, and 6) catalyst durability. Ford has also continued their laboratory investigation of cycling the A/F ratio about stoichiometry.

For catalysts which had undergone 100 hours of accelerated engine dynamometer aging, gross NOx conversion was shown to be substantially higher with noble metal loadings of 50 gm/cu ft. than with loadings of 20 gm/cu ft. for a range of Pt/Rh ratios as shown in Figure Ford-1. Ford suggested that HC and CO control were not substantially affected by noble metal loading. No HC or CO data were provided to support this conclusion. The maximum loading of 50 gm/cu ft. is not considered to be excessively high. For example, this loading was used by Ford in 1975 production vehicles. At a constant noble metal loading, gross NOx conversion apparently was not affected by varying the Pt/Rh ratio from 5/1 to 19/1; however, the net NOx conversion efficiency appeared to increase greatly for the high Rh compositions as shown in Figures Ford-2 and Ford-3. The difference between the gross and net efficiencies is ammonia emissions. EPA cannot be certain that Pt/Rh ratio is responsible for these differences between gross and net NOx conversion efficiency as the catalysts were not thoroughly described by Ford. HC and CO efficiency were not affected by the Pt/Rh ratio, according to Ford.

Figure Ford-2*

% Gross NOx Conversion Vs. Precious Metal Loading at Constant Pt/Rh Ratios at 14.5 ± 1.0 A/F at 1.0 Hz

* from Ford Status Report, December 1976, section IIB, page 33.

100 Hours Accumulated Aging

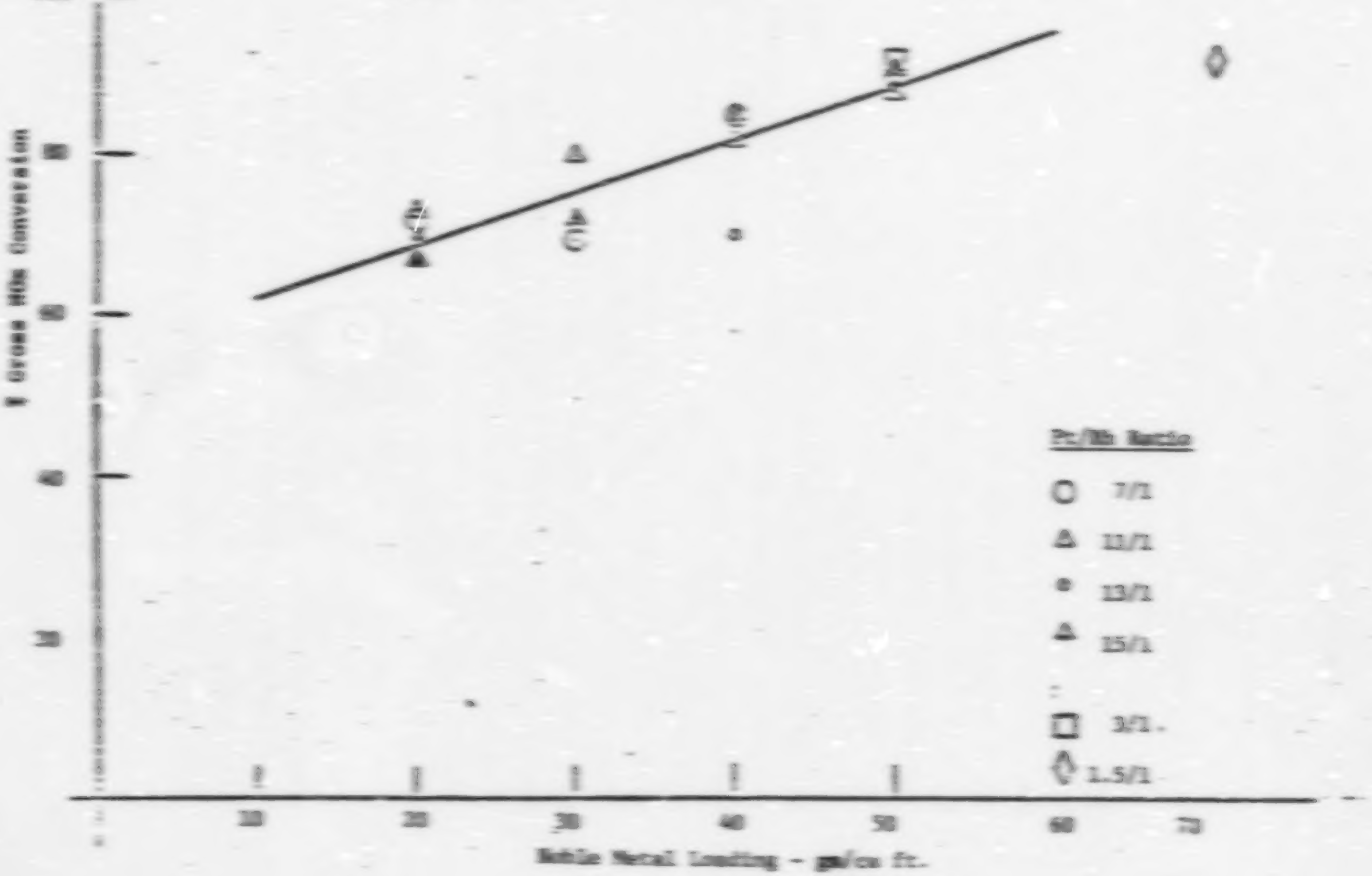
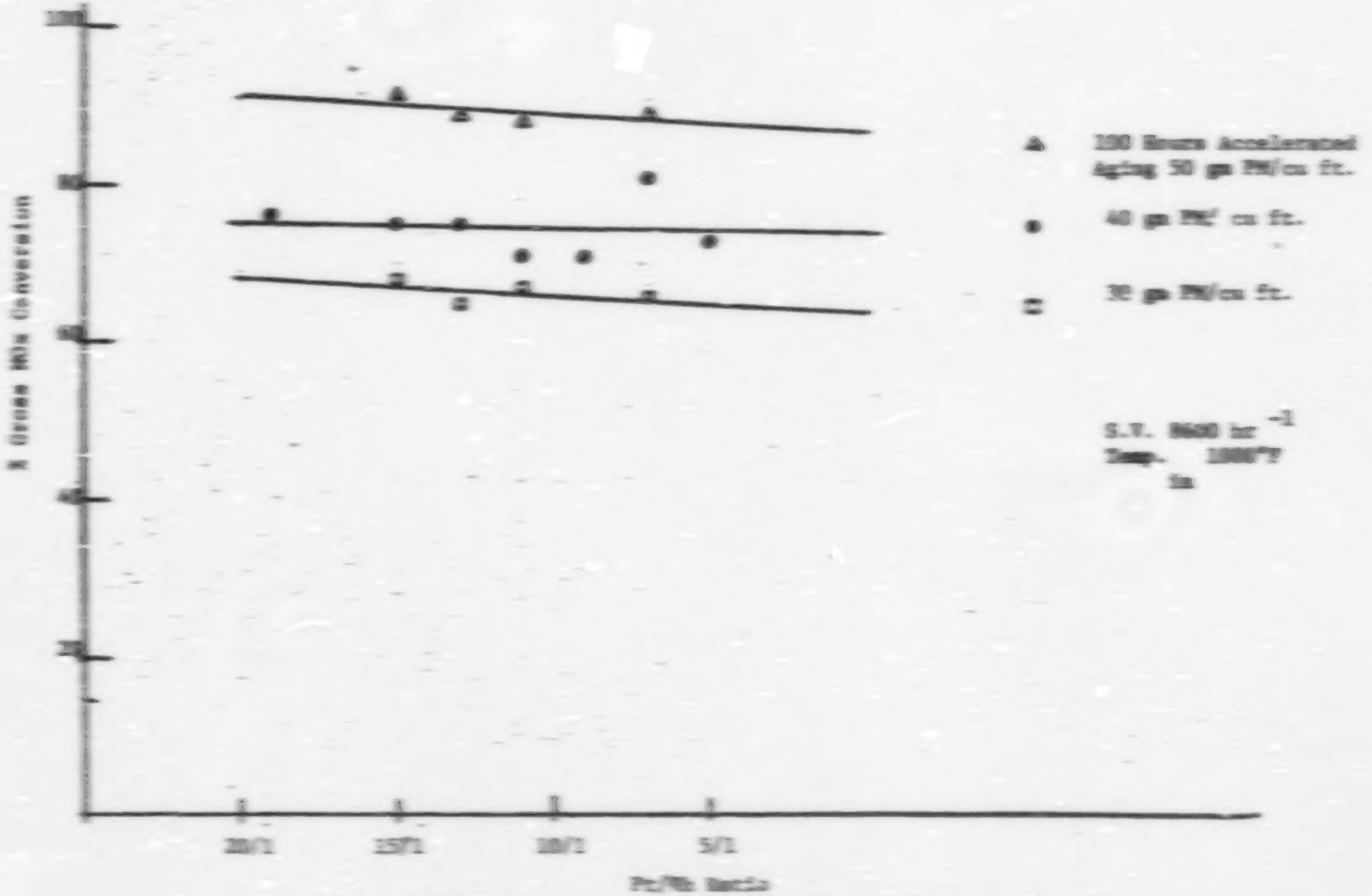


Figure Ford-2*

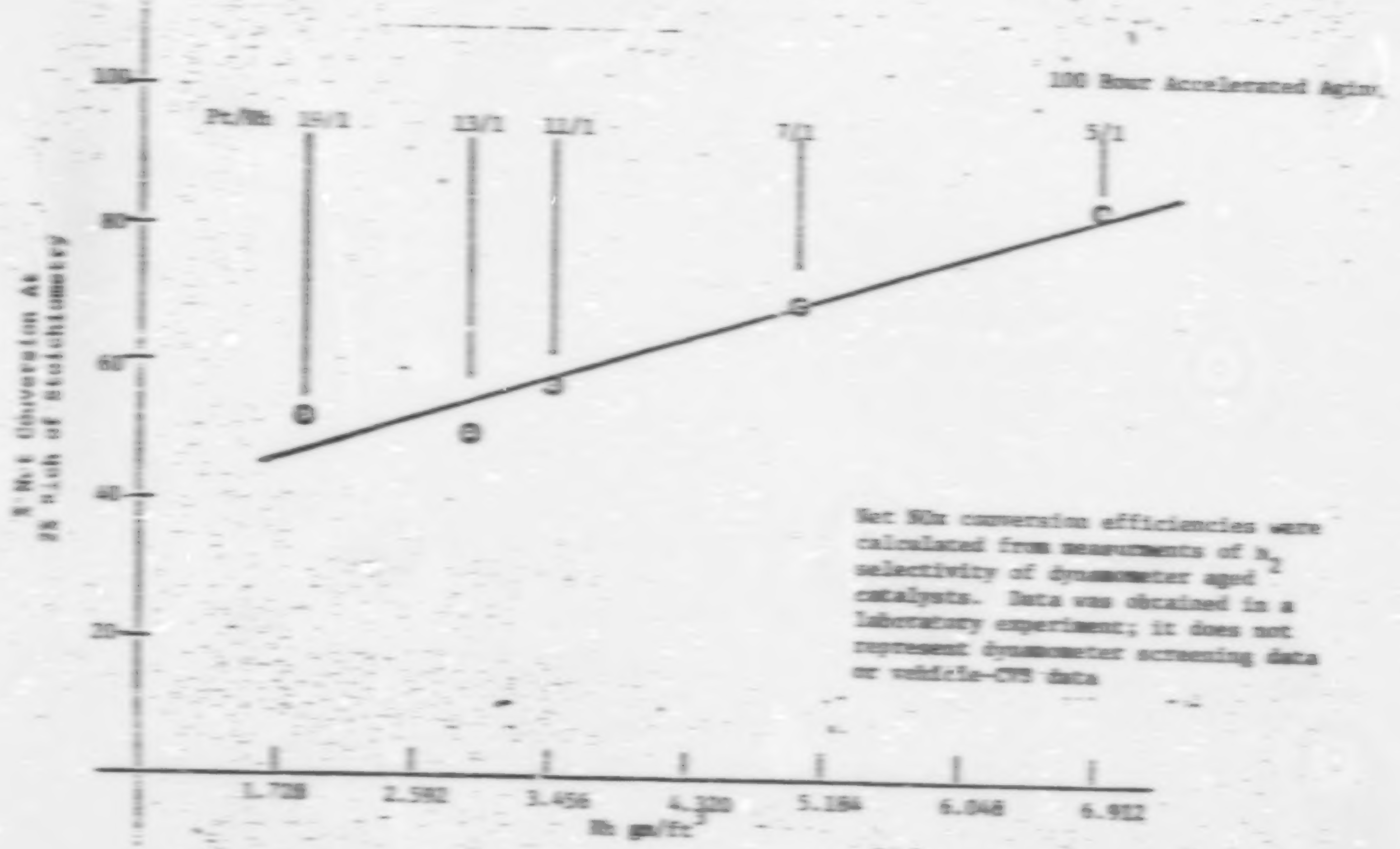
% Gross NOx Conversion vs. Pt/Rh at Constant PM Loadings
at 14.5 ±1.0 A/F at 1.0 Hz



* from Ford Status Report, December 1976, Section IIB, page 11.

Figure Ford-3*

% Net NOx Conversion Vs. Rh Loading (gm/ft^3)
at Constant PM Loading (Pt+Rh = 40 gm/ft^3)



Net NOx conversion efficiencies were calculated from measurements of N_2 selectivity of dynamometer aged catalysts. Data was obtained in a laboratory experiment; it does not represent dynamometer screening data or vehicle-CVS data

* from Ford Status Report, December 1976, section III, page 11.

The steam reforming and water-gas shift components help expand the 3-way catalyst window on the rich side of stoichiometry. The four components tested for their activities were rhodium (Rh), rhenium (Re), nickel (Ni), and ruthenium (Ru). Rh and Ru were found to have good steam-reforming activity. Ni and Ru were found to have significant water-gas shift activity. The results are shown in Tables Ford-1 through Ford-4.

The use of oxygen storage components and air-fuel ratio cycling also seems to widen the 3-way catalyst window on the rich side of stoichiometry at 80% conversion efficiency as shown in Figure Ford-4. Though the peak 3-way conversion efficiency is reduced by 2-3%, the air-fuel operational window is increased by a factor of three. Ford says that the cyclic air-fuel ratio work is not being conducted for the purpose of developing air-fuel metering systems, but only to quantify the effects of air-fuel ratio cycling in current developmental systems. Only one material was discussed by Ford as an oxygen storage component and that was rhenium (Re).

The major result of catalyst deactivation generally seemed to be the collapse of the HC efficiency curve on the rich side of stoichiometry as shown by results of fresh and aged catalysts of comparable type in Figure Ford-5. The reason for this loss in HC conversion efficiency is shown in Table Ford-5. Lead, sulfur, and phosphorus contents were all higher in the 1974/1975 durability fuels than in the simulated 1977 fuel. Apparently one or more of these contaminants poison the 3-way catalyst for HC oxidation. The CO and gross NOx efficiency curves were not greatly affected by aging.

Table Ford-1*

Effect of Temperature on Steam-Reforming Reaction Fresh Catalyst

Experimental Conditions:

S.V.	60,000 hr^{-1}
H_2	0.5%
CO_2	8.0
H_2O	7.0
C_2H_6	1000 ppm
C_3H_8	500
N_2	balance

Catalyst	Percent Conversion of Hydrocarbon (°C) 350	400	450	500	600
Ruthenium	22	33	43	54	65
Rhodium	69	77	84	88	90
Rhenium	11	13	17	17	17
Nickel	12	13	14	20	45
M257	84	88	91	93	95
M26BA	66	69	73	75	80
M196	66	76	81	84	88

Table Ford-2*

Effect of Hydrocarbon Concentration on Steam-Reforming Reactions Fresh Catalyst

Experimental Conditions:

S.V.	60,000 hr^{-1}
Temp	450°C
H_2	0.5%
CO_2	8.0
H_2O	7.0
C_2H_6	330-1000 ppm C
C_3H_6	170-500 ppm C
N_2	balance

Catalyst	Percent Conversion of Hydrocarbons at Inlet Hydrocarbon Concentration (ppm) 500	1000	1500
Ruthenium	38	58	63
Rhodium	82	84	86
Rhenium	18	17	17
Nickel	31	19	14
M257	84	88	91
M26BA	71	73	73
M196	78	81	80

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* From Ford Status Report, December 1976, Section IIB, page 69

Table Ford-3**

Effect of Temperature on Water-Gas Shift Reaction Fresh Catalysts

Experimental Conditions:

S.V.	60,000 hr^{-1}
CO	1.5%
H_2	0.5
CO_2	8.0
H_2O	7.0
N_2	balance

Catalyst	Percent Conversion of CO (°C) 350	400	450	500	600
Ruthenium 0.18% on Corning monolith	62	64	65	76	58
Rhodium, 0.13% " " "	no water-gas shift activity				
Rhenium, 0.2% " " "	no water-gas shift activity				
Nickel, ≈5% " " "	20	56	71	71	52
M257*	63	58	62	64	50
M268A	12	46	64	63	44
M196	36	66	85	84	82

*Extreme spread in results. Figures given are a conservative average.

Table Ford-4**

Effect of CO and H_2 Concentration on Water-Gas Shift Activity Fresh Catalysts

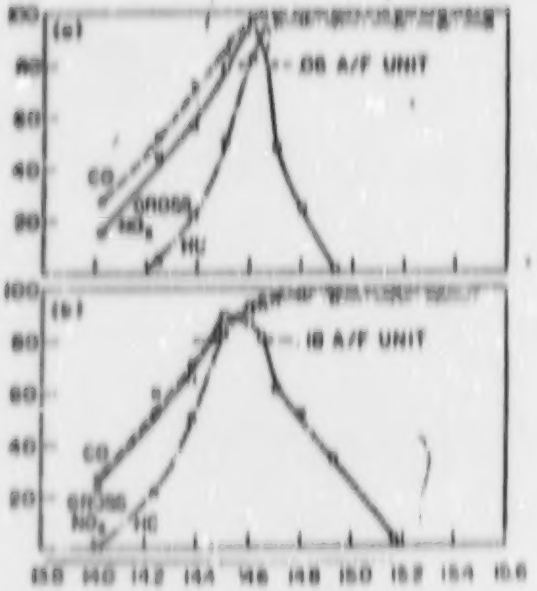
Experimental Conditions:

S.V.	60,000 hr^{-1}
Temp.	450°C
CO	0.5-2.5%
H_2	1/3 of CO
CO_2	8.0%
H_2O	7.0
N_2	balance

Catalyst	Percent CO Conversion at Inlet CO Concentration (%) 0.5	1.0	1.5	2.0	2.5
Ruthenium	74	74	65	60	50
Rhodium	No water-gas shift activity				
Rhenium	No water-gas shift activity				
Nickel	82	76	71	68	65
M257	76	69	62	56	50
M268A	64	62	61	60	55
M196	50	67	85	52	33

**From Ford Status Report, December 1976, Section II B, page 68

Figure Ford - 4



A/F

Figure Ford-4* Effect of Air-Fuel Modulation on a Catalyst with Oxygen Storage Capability (a) without modulation, (b) sawtooth modulation 1.0 Hz. Modulation amplitude ± 1.0 A/F unit; catalyst inlet temperature 1000°F (538°C); S.V. 30,000 h^{-1}; catalyst after 50 h of testing.

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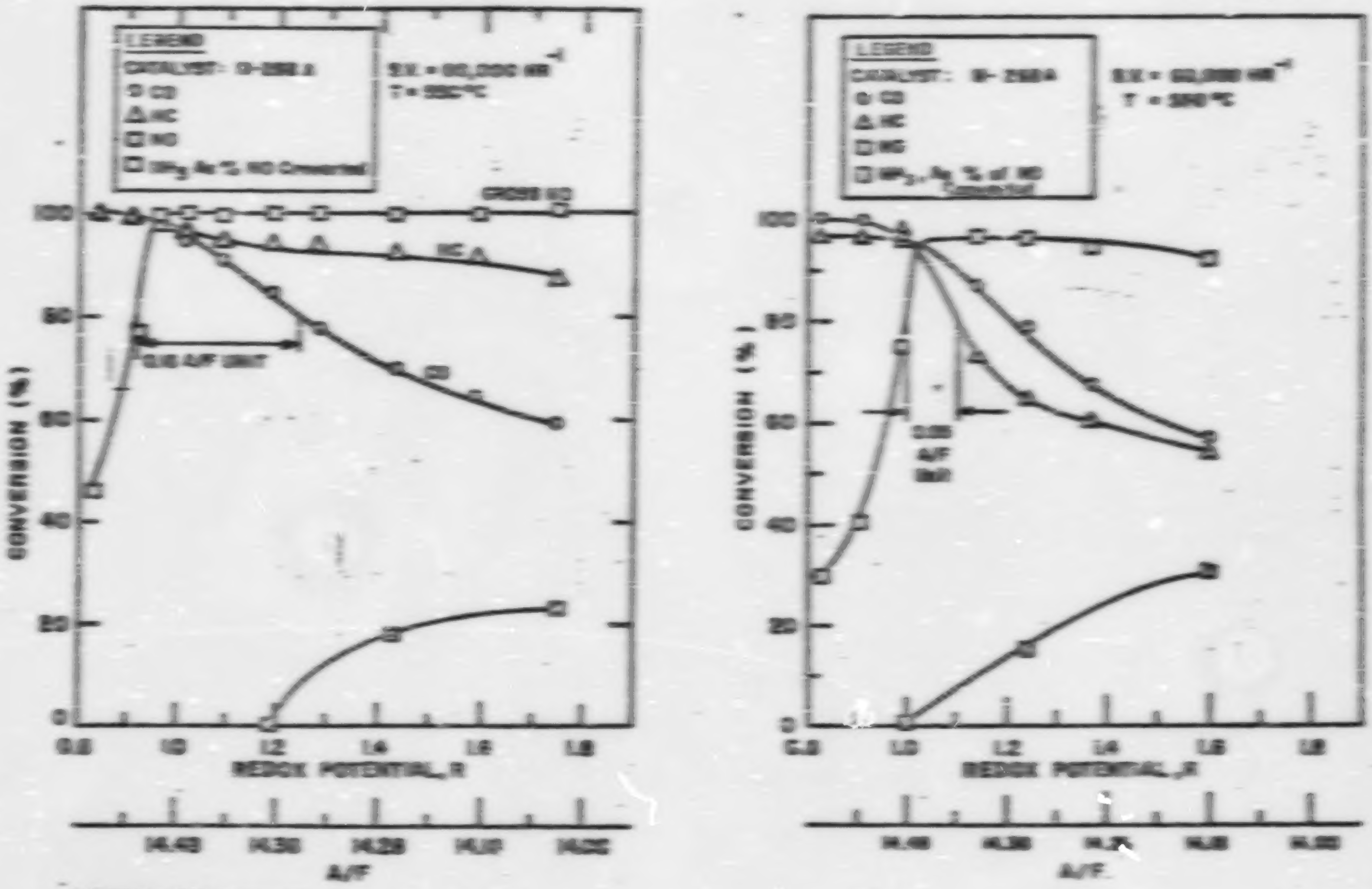
* from Ford Status Report, December 1976, section IIB, page 16.

Figure Ford-2**

Effect of Catalyst Aging



X-2088 FRESH CATALYST

AGED X-2088 CATALYST

Pretreatment: 25,000* Simulated Miles Durability Aging with Simulated 1977 Certification Fuel

* Simulated Durability miles.

** From Ford Status Report, December 1976, section III, pages 20 and 21.

Table Ford-5**

Selectivity and Activity of Fresh and Aged 3-Way Catalysts

A. Width of Window for 3-Way Selectivity

Catalyst	Width of Window for 80% Conversion of Net NO, CO and HC at 550°C and 60,000 Hour^{-1} space-velocity. (A/F Unit)			
	Fresh	25,000 Simulated Miles with Lead-Sterile Isooctane *	25,000 Simulated Miles with Simulated 74/75 Certification Fuel *	25,000 Simulated Miles with "Simulated" 76/77 Certification Fuel *
M-15202-3	0.16	0.13	0	0.06
M-253	0.05	0.05	0	0.04

B. Activity

Temperature (°C) for Simultaneous 50% and 80% Conversion Net NO, CO, HC at Mean A/F Ratio

Catalyst	50% a	80% a	50% b	80% b	50% c	80% c	50% d	80% d
M-15202-3	280	295	280	300	340	could not be reached	280	350
M-253	225	245	N.R.	455	430	could not be reached	225	550

* simulated Pulsator Miles

** From Ford Status Report, section IIB, page 47

Ford completed 300 hours of accelerated engine dynamometer aging on 23 different 3-way catalysts. Five of the catalysts had peak NOx conversion efficiencies greater than or equal to 90% at 300 hours. An additional 5 catalysts had peak NOx efficiencies between 80 and 89% at 300 hours. Six more catalysts had efficiencies between 70 and 79%. The 80% efficiency windows of operation were not reported. The aging was conducted at stoichiometry, except for 20 minutes per cycle of thermal degradation conditions. The remaining 220 minutes per cycle were divided between idle (15 minutes) and catalyst poisoning condition (205 minutes). The fuel contained 0.027 gm/gal Pb, 0.003 gm/gal P, and 0.045 weight % S.

Oxidation Catalysts

Ford apparently believes that their oxidation catalyst systems are good enough for any anticipated HC and CO emission levels. The only reported efforts on oxidation catalysts were to reduce the noble metal loading from an already low 25 gm/cu ft. to 15 gm/cu ft. Ford suggested that this reduction in loading probably could be made without deterioration in catalyst performance. For a 160 cubic inch catalyst, this would represent about a $4.00 cost savings in noble metal.

Other data concerning noble metal loading were submitted in Ford's previous status report. That testing used noble metal loadings up to 50 gm/cu ft. and showed distinct improvements in catalyst light off temperature with higher loadings. These data are shown in Table Ford-6. Losses in hot HC conversion efficiency at 300 hours are also shown to be minimized with higher loadings.

Table Ford-6**

Effect of Noble Metal Loading

Metal Loading (GM/FT^3)	Conversion Efficiency (800°F 40K HR^{-1}) HC 25 HR	HC 300 HR	CO 25 HR	CO 300 HR	Lightoff Temperature °F HC 25 HR	HC 300 HR	CO 25 HR	CO 300 HR
10a/	87.1	69.8	99.0	90.0	604	685	585	670
15	87.8	74.1	98.0	93.9	581	684	559	669
20a/	89.1	78.6	98.8	71.9	569	685	546	617
25	89.5	79.1	97.9	93.5	517	612	498	591
30 a/	88.8	82.0	97.3	93.8	546	595	528	579
40	88.8	79.1	97.9	89.6	534	579	513	561
50	90.4	81.8	95.6	90.7	523	589	507	568
50*a/	91.3	83.3	99.5	98.3	508	565	491	548

*/ 1975 Production type catalyst included as a reference catalyst in all tests.

a/ 2 test average

** From Ford Status Report, December 1975, Section II 6, page 2.

Dual Catalyst

Ford efforts on dual catalyst systems have essentially stopped. The only testing which was reported was some sulfate testing on a Gould GEM-68 catalyst-equipped vehicle. The reported sulfate emissions of vehicle 112T531 were 58, 72, and 76 mg/mi over the SET-7 with 0.03 wt. % sulfur fuel. The hot FTP results of the 400 CID, 5000 lb. IW vehicle were reported to be 0.33 HC, 0.46 CO, 0.25 NOx, 10.3 MPG_u.

Ford has dropped the Gould program until Gould can demonstrate improved sulfur tolerance and improved efficiency.

Questor System

Since the most recent tests of the Questor equipped Pinto (shown in Table Ford-7) were not particularly successful, Ford has decided to "postpone" this program.

Table Ford-7

VIN	CID	# Tests	Miles	HC	CO	NOx	MPG_u
38P35	2.3 litre	3	0	0.10	2.70	0.30	16.9
		6	1000	0.10	3.77	0.23	15.8
		4	5000	0.08	3.36	0.61	16.5
		6	10000	0.31	11.03	1.43	17.3
		4	10000	0.17	6.92	1.30	17.6*

* Enriched idle CO

Electronic Control Systems

A system combining electronic control of sonic EGR and spark will be introduced in 1978. Another electronic control system under development will also add electronic control of the air-fuel metering system. This combination of electronic control systems has been anticipated for some time. Ford maintains that the verification of component durability is perhaps the biggest problem for this type of system.

In addition to the electronic EGR system, a pneumatically-operated, sonic EGR system is under development. Possibly this system is being considered as an improved EGR system for vehicles which will not be converted to electronic controls. Both systems are actuated by air pressure from the air pump, and according to Ford, the sonic valve provides a constant EGR flow at a given valve position with varying manifold vacuum. Previously submitted data showed large HC reductions with sonic EGR. Ford representatives indicate that this is due to better EGR control at light load operating conditions. Current systems were said to meter excessive amounts of EGR at light load. Since calibrations are based on higher load conditions (high NOx emitting conditions) and current systems cannot reduce the EGR rate fast enough with decreasing load, unnecessarily high HC emissions are emitted.

Ford reported that a number of actuation devices for feedback carburetion were evaluated, and that based on packageability, control, response, hysteresis, and cost, a stepper motor design has been selected for durability testing. Very few of these evaluations were presented to EPA.

In Table Ford-8, an electronic fuel injection (EFI) system is compared to a sonic, electronic fuel metering system (EFM). Both were feedback systems and used similar Bendix electronics. The major difference was that the EFI system used eight injectors, one at each intake valve, and the EFM had only two injectors mounted in a sonic throttle body.

Table Ford-8*

EFI Versus Sonic EFM

	EFI	Sonic EFM
Engine out emissions (75 FTP)	4.35 HC, 31.46 CO, 1.6 NOx	4.47 HC, 44.88 CO, 2.97 NOx
Tailpipe emissions (75 FTP)	0.36 HC, 1.78 CO, 0.62 NOx	0.45 HC, 2.91 CO, 0.90 NOx
MPG_u	12.1	11.2
MPG_h	16.2	17.0
MPG_c	13.6	13.2
± 2 σ air-fuel ratio band over hot 505	± 0.40	± 0.34
part throttle octane requirement	86	92
wide open throttle octane requirement	95	97

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* From Ford Status Report, December 1976, Section III B, page 5.

Both systems were tested on 400 CID Elites with 3.00:1 rear axles at 4500 pounds IW. The EFI system was superior in all respects except in highway fuel economy and the operational air-fuel ratio band. Engine out emissions were not particularly good for either system. The EFM might improve with further development and the speed-density EFI is not the most technologically advanced fuel injection system.

Another comparison was presented between the sonic EFM and a 4350 feedback carburetor (FBC). The results are shown in Table Ford-9. Both were 400 CID vehicles with automatic transmissions and 2.50 rear axles at 5000 pounds IW. Both vehicles had cooled backpressure EGR and 3-way plus oxidation catalyst systems. The sonic EFM used a single plane intake manifold and the FBC used a dual plane intake.

Table Ford-9

Sonic EFM Versus the 4350 FBC*

	EFM	FBC
Tailpipe ('75 FTP)	0.27 HC, 1.2 CO, 0.71 NOx	0.27 HC, 1.6 CO, 0.68 NOx
± 2 air-fuel ratio band	±0.5-0.6	±0.5-0.6
MPG_u	12.0	12.7
MPG_h	18.4	19.2
MPG_c	14.2	15.0
0-60 time (sec)	12.6	12.2
25-60 time (sec)	8.5	8.4
1/4 mile test (sec)	18.6	18.4
driveability (avg/min)	6.9/5	6.1/6.0
part throttle octane requirement	94	88
wide open throttle octane requirement	95	88

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*From Ford Status Report, December 1976, Section III B, page 7.

The FBC performed very well, and demonstrated the potential for utilizing feedback carburetion at 0.41 HC, 3.4 CO, 1.0 NOx on vehicles of high inertia weight and with large engines. It provided better fuel economy, performance, and octane requirement than the EFM at nearly constant emissions. The fuel economy and emissions of the EFM vehicle are much improved over the EFM vehicle in Table Ford-8. The vehicle in Table Ford-9 is at a higher inertia weight, but does have a lower axle ratio. The changes in EFM performance are the result of additional development efforts on the system. The fuel economy of the comparable 1977 Federal certification vehicles are shown in Table Ford-10. It should be noted that the fuel economy of the FBC vehicle was 0.3 MPG_c better than the best comparable 1977 Federal vehicle from Ford with same displacement, inertia weight, axle ratio, and transmission. The emissions of the FBC vehicle were much lower than the 1977 Federal vehicle.

Based on the previously mentioned testing, sonic EFM has been dropped from further consideration in programs directed toward 1.0-2.0 NOx.

Table Ford-10

4,000 or 5,000 Mile Fuel Economy of 1977 Federal Certification Vehicles

Vehicle	IW	MPG_u	MPG_h	MPG_c	VIN
Fuel economy/data	4500	12.2-13.0	16.0-18.5	13.7-15.0	701-400-F-63*
Durability	4500		Not Available		
Fuel economy/data	5000	11.8-12.7**	14.9-18.2**	13.0-14.7**	7A1-400-G-69**/701-400F-47
Durability	5000	11.3-12.0***			

---

* 2.50 axle, not 3.00 axle
** running change
*** 2.75 axle ratios

The average driveability of the FBC was somewhat poorer than the EFM, though still good.

The minimum driveability objective of a rating of six for this development testing is higher than Ford has considered as acceptable in the past and may suggest that Ford is trying to improve the driveability of their vehicles.

Other Development Efforts

Plans for a dual displacement, 300 CID, six cylinder engine were revealed. No test results or operational details were submitted, though Ford has reportedly* accumulated about a half million miles of durability on the system. The device was developed to improve vehicle fuel economy by reducing the number of operational cylinders (and thus operational displacement) when high power output is not required of the engine. The system is automatically controlled by an electronic system which reportedly[**] has eliminated problems with engagement and disengagement of the cylinders.

The system is to be introduced within a few years on light truck, and fuel economy is said to be increased by 10 to 20% according to the above-referenced articles.

Sonic Carburetion

Ford tested a 1V, open loop, sonic carburetor which was calibrated to stoichiometry on a 250 CID Comet at 3500 IW. Other emission control equipment included EGR and a 3-way catalyst. While the system did hold a close air-fuel ratio band around stoichiometry (± 2% = ± 0.25), the reported emissions were not impressive. Best results using the 3-way catalyst were reported to be 0.71 HC, 7.4 CO, 0.61 NOx, 14.0 MPG_u and 1.23 HC, 14.0 CO, 0.39 NOx, 14.0 MPG_u.

Modulated Secondary Air Injection

Ford has evaluated the use of modulated secondary AIR using simulated, hot CVS results which were generated from engine maps using full AIR and no AIR. A simulation for a 3000 lb IW Pinto with an automatic transmission showed fuel economy improvements of about 3 to 10% for modulated AIR over full AIR at constant HC and NOx emissions for a range of NOx emissions from 1.0 to 2.0 gm/mi. The biggest fuel economy advantage was

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[*] Machine Design, 21 October 1976.

[**] Time, 4 October 1976.

at the lowest NOx level. About 9-10% improvement in fuel economy was shown for modulated AIR as compared to no AIR over the same NOx range.

Another set of simulated data for the 3000 lb IW Pinto is shown in Table Ford-11. Improvements in HC, NOx, and MPG are predicted with modulated AIR compared to both the no AIR and full AIR configurations.

Since CO emissions were not mentioned by Ford, it is assumed that adequate CO control was either assumed or maintained by Ford in all configurations. Also, Ford did not discuss the details of the hardware that they would use to implement the modulated AIR system on a vehicle.

Fast Burn

Little success has been achieved in increasing the charge burn rate by modifications to the combustion chamber geometry, but fast burn work for Ford will be continued at Ricardo. The further efforts are to study the number and location of spark plugs. If successful, these efforts could yield improved fuel economy and higher EGR tolerance which could provide reduced NOx emissions.

Exhaust Heat Conservation

Port liners were installed on a Pinto with a 2.3 litre engine. Exhaust gas temperatures at the port outlet were increased by 75 to 100°F; but the expected HC reductions were not obtained. In some cases HC was even increased by the port liners. Ford attributed the poor HC performance to insufficient residence time in the exhaust manifold. The reported data were steady state, engine dynamometer results. No vehicle testing was reported.

Table Ford-11*

Unconstrained Vehicle Capabilities From Engine Mapping

Pinto	Min. HC (gm/mi)	Min. NOx (gm/mi)	Projected Max Fuel Economy (MPG)**
3000# IW A/T 3.4 AR			
Sec. Air Only	0.73	0.73	24.25
No Sec. Air	0.70	0.74	24.55
Modulated Sec Air	0.57	0.69	24.77

Pinto			
3000# IW M/T 2.79 AR			
Sec Air Only	1.46	0.44	28.68
No Sec Air	0.97	0.41	28.71
Modulated Sec Air	0.87	0.36	29.00

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* from Ford Status Report, December 1976, Section III G, page 10.

** MPG is for CVS-Hot.

Table Ford-12*

	400 CID Baseline Engine	
	Afterburner 30° BTC	Spark Retard (From 30° BTC)
Speed/Load (rpm/lb. ft.)	Fuel increase/ HC reduction	Fuel increase/ HC reduction
650/40	40%/53%	10%/10%
650/40	50%/65%	20%/45%
650/40	80%/83%	
1000/40	26%/54%	5%/42%
1000/40	31%/66%	15%/78%
1000/40	50%/90%	

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* from Ford Status Report, December 1976, Section III H, page 26

Table Ford-13**

Conventional Lean Burn Versus the CVCC

	'75 FTP - gm/mi.			Fuel Economy			
	HC	CO	NOx	MPG_u	MPG_h	MPG_c	IW
2.3 litre M/T Pinto L.B. Vehicle (T511)	1.32	7.4	0.72	21.2	30.5	24.6	3000#
Reference EARB CVCC Vehicle 2.3 litre M/T Pinto	1.30	7.7	0.82	21.1	29.2	24.1	3000#

** from Ford Status Report, December 1976, Section III J, page 3

Exhaust Afterburner

Engine dynamometer testing was reported on a 400 CID engine with an exhaust afterburner as shown in Figure Ford-6. Sufficient fuel was injected into the afterburner to yield exhaust gas temperatures of about 1200°F. The test results shown in Table Ford-12 were not favorable when compared to the results obtained with spark retard. The reported data are, however, very limited and may not represent the optimum operation of the afterburner. For example, NOx emissions were not considered in the Ford analysis.

CVCC Versus Conventional Lean Burn at 1.0 NOx

This testing was conducted to see if a conventional lean burn vehicle could achieve 0.41 HC, 3.4 CO, 1.0 NOx with fuel economy equivalent to a similar CVCC prototype at the same emission level. The CVCC vehicle was not described. The lean burn vehicle had a considerable number of advanced emission control components. These included electronic EGR, port liners, a 140 cu in. thermal reactor, and an oxidation catalyst.

The input emissions to the catalyst are presented in Table Ford-13 (which is found on the previous page). The emission results are comparable and the fuel economy results are also about equivalent. Tailpipe emissions were not reported for either vehicle. The biggest question in this testing concerns the optimization of the CVCC vehicle. In light of the substantial improvements in fuel economy which have recently been reported by Honda, it is likely that the fuel economy of the Ford 2.3 litre CVCC engine could also be improved. Another question is the cost of the control system. It would seem possible that the cost of the emission control system on the CVCC would not be as expensive as the control system on the conventional engine.

H.C. EXHAUST AFTERBURNER INSTALLED ON A 400 CID, 2V

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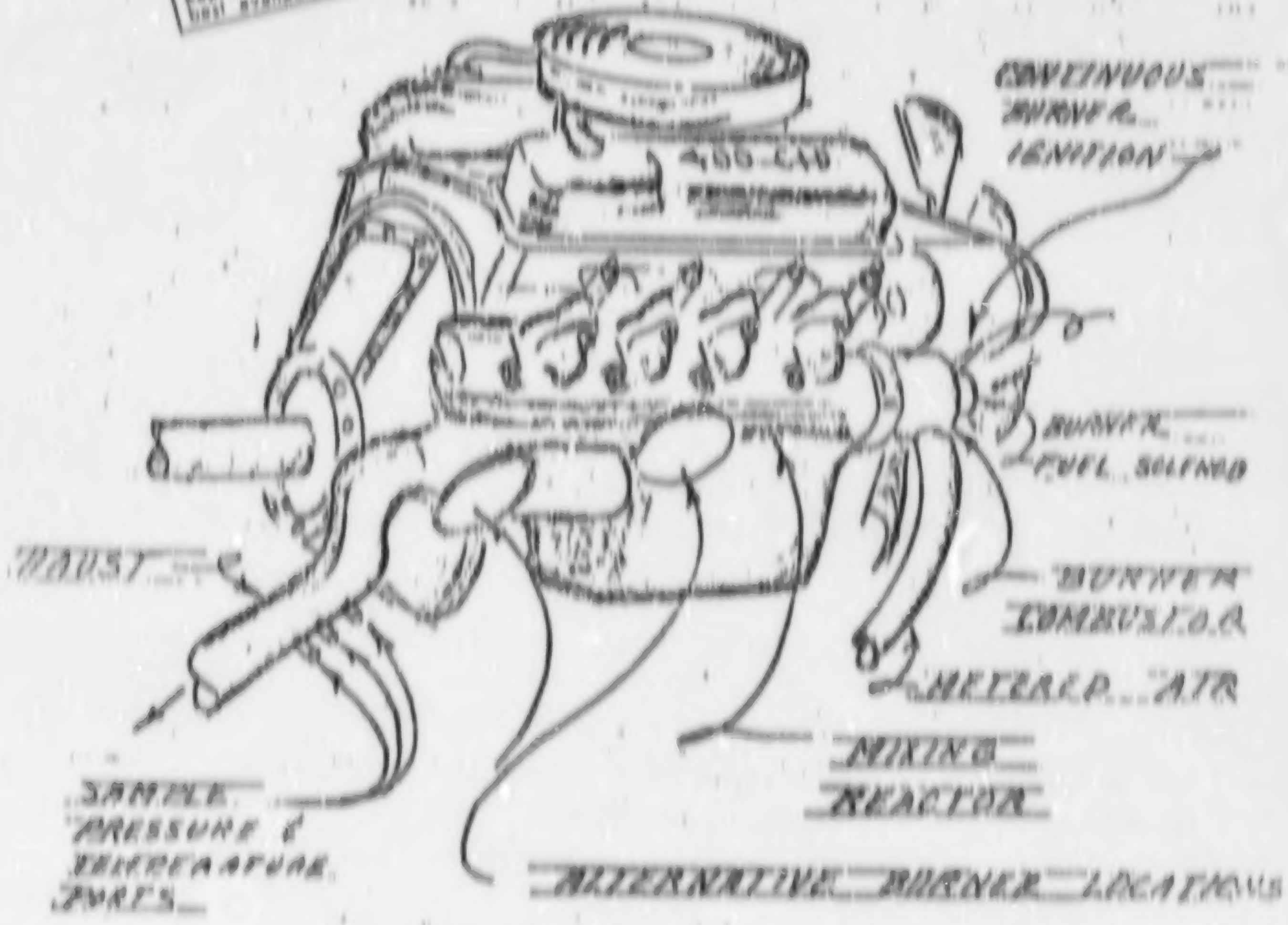
CONTINUOUS BURNER IGNITION
400-CID
BURNER FUEL SOLENOID
EXHAUST
BURNER COMBUSTOR
METERED AIR
MIXING REACTOR
SAMPLE PRESSURE & TEMPERATURE PORTS
ALTERNATIVE BURNER LOCATIONS

Figure Ford-6*

* From Ford Status Report, December 1976, section IIIB, page 21.

Lean Reactor Size Comparison

The conventional lean burn engine from the CVCC comparison testing was then modified to include a 280 cu in. reactor, twice the volume of the original reactor. No calibration changes were made. As seen in Table Ford-14, the reactor out emissions of HC were reduced 33% and CO were reduced 27%. These reductions could be converted to further fuel economy gains for the conventional lean burn system if catalyst out emissions are not degraded by slower catalyst light off or reduced feedgas temperatures.

Table Ford-14

Reactor Size Comparison*

	HC	CO	NOx	MPG_U	MPG_H	MPG_C
2.3 litre, L.B. Vehicle 200% Volume Reactor	0.88	5.4	0.70	21.8	30.6	25.0
Reference 2.3 L.B. Vehicle 100% Volume Reactor	1.32	7.4	0.72	21.2	30.5	24.6

* From Ford Status Report, December 1976, Section III J, page 3.

Alternate Engines

PROCO

Recent engine mapping efforts on the PROCO engine have been in the area of reducing HC emissions at NOx levels of 1.0 and 0.4 with the Ford high injection rate fuel injection system. The only vehicle testing which was reported at 1.0 NOx is shown in Table Ford-15. These results are for a 460 CID PROCO in a 5000 IW vehicle with an automatic transmission and a 2.75 rear axle. The tests were conducted with a 324 cubic inch oxidation catalyst which had been aged 4000 miles. The fuel economy results of the best comparable 1977 Federal certification vehicle* of similar displacement, inertia weight, and transmission type are 13.0 MPG_u, 18.4 MPG_h, 15.0 MPG_c. Thus a 21% increase in composite fuel economy is shown when compared to the 1977 vehicle. This comparison should, however consider that the peak power output of the 400 CID PROCO might be less than that of the conventional 400 CID engine, because the PROCO may not run as rich as a conventional engine at peak power and may have more friction to overcome. The tailpipe emissions of the PROCO are very good; however, the engine out HC emissions may still be quite high. Over a hot start test, engine-out HC was reported to be 2.1 - 2.4 gm/mi. Apparently the large catalyst is capable of doing the required oxidation. Of the 0.22 HC on the cold start test, 32% was reported to be methane.

Table Ford-15*

PROCO Test Results

Tailpipe Emissions (75 FTP)	0.22 HC, 0.1 CO, 0.78 NOx
MPG_u	15.5
MPG_h	22.7
MPG_c	18.1
Performance	
0-10 seconds	429 ft
0-60 mph	12.8 sec
50-80 mph	14.1 sec
Driveability	
Average	6
Minimum	5+

* From Ford Status Report, December 1976, Section IV A, pages 15 and 16.

These test results are an example of the use by manufacturers of improved emission controls (in this case a larger catalyst) on engines which may have some emissions problems, but are considered to have other attractive properties.

No engine or vehicle testing was reported on either the injectors developed for the PROCO by AMBAC, Robert Bosch, and Nippondenso or the three injection pumps developed by Robert Bosch. Single cylinder engine testing was done on the injection pump developed by Holec, but secondary fuel injection problems were encountered.

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* VIN 7A1-400-G-81, 2.47 axle ratio instead of 2.75 axle ratio.

Electronic control systems are now being developed for air-fuel metering, spark, and EGR control. Ford stated that the necessary mapping of the 400 PROCO has been completed. The Eaton valve deactivation device has been applied to the 400 PROCO to make the V-8 capable of operating on either 4, 6 or 8 cylinders. Ford states that the Eaton device alone will reduce the HC emissions about 15 to 30% over the FTP and will increase fuel economy by 10%.

Based on engine mapping, the 0.4 NOx calibrations were projected to yield the hot start test results shown in Table Ford-16. Based on similar projections and later vehicle testing at 1.0 NOx, the HC projections may be optimistic.

CVCC

Ford stated that "if an ultimate 1.0 NOx level is adopted by Congress, then the application of prechamber engines might be considered for subcompact models". Development efforts were continued on both the 2.3 litre and 1.6 litre CVCC engines.

A configuration of the 2.3 litre CVCC targeted for statutory emission levels was tested. The emission control system utilized electronic EGR to the main and prechamber; exhaust port liners; a 140 cu in. thermal reactor; a 135 cu in., Engelhard TWC-16, 3-way catalyst; a 135 cu in. Engelhard II C, oxidizing catalyst; and switched secondary AIR. This 3000 pound IW Pinto had a four speed transmission and a 2.79 axle ratio. The test results were reported to be 0.36 HC, 1.7 CO, 0.15 NOx, 22.7 MPG_u, 31.5 MPG_h, 26.0 MPG_c. This represents a 2% loss in economy when compared to the most nearly comparable '77 Federal certification vehicle* which had

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* VIN 722-2.3-F-22.

Table Ford-16*

PROCO CVS-H Projections
Fast Rate vs. Std. Rate at 0.4 gm/mi NOx

400 CID
5000 lb. IW
A/T, 2.75 Axle Ratio
(75 grains H_2O/lb. dry air)

Injection Rate	HC gm/mi	CO gm/mi	NOx gm/mi	CVS-H MPG
Std.				
20:1 A/F Calib.	2.5	8.6	0.32	16.0
18:1 A/F Calib.	2.1	9.6	0.33	15.9
Fast				
20:1 A/F Calib.	2.1	12.5	0.33	16.1

NOTES:

1) The fast rate injection resulted in poor combustion at A/Fs richer than 18:1 at part load, thus no part load tests were carried out at 14.7 A/F.

2) All projections include an A/F of 14.7 at the highest torque conditions of the CVS cycle.

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* from Ford Status Report, December 1976, Section IV A, page 9.

a 3.18 axle ratio, and achieved 22.9 MPG_u and 32.5-32.8 MPG_h. The air-fuel calibration and feedgas emission levels of the vehicle were not mentioned and thus the dependence on the 3-way catalyst for NOx control could not be determined.

This vehicle demonstrates substantial development activity for the CVCC concept. This vehicle, without the electronic EGR or reactor and at 2750 pounds IW, was previously reported to achieve 0.27 HC, 1.5 CO, 0.33 NOx, 24.0 MPG_u. If Ford's efforts continue on this calibration, it may represent a possible application for their modulated AIR concept as well. The Honda calibrations of CVCC vehicles at these emission levels have been very lean and have not utilized 3-way catalytic emission control systems.

A vehicle with a 2.3 litre engine calibrated to 1.0 NOx and used a lean calibration, EGR, and an oxidizing catalyst. The 2750 pound IW vehicle was reported to achieve 0.40 HC, 2.2 CO, 1.01 NOx, 24.4 MPG_u. The vehicle with a 1.6 litre CVCC engine which was previously reported to have achieved 31.3 MPG_u, 48.0 MPG_h, and 37.0 MPG_c, at 2000 pounds IW was reported at 0.43 HC, 2.6 CO, 0.86 NOx, 31.0 MPG_u. This vehicle also used a lean calibration, port liners, a thermal reactor, and an oxidizing catalyst.

Diesel

A feasibility study has been conducted on the Dieselization of the 351 CID gasoline engine. To maintain maximum interchangeability of parts, the Diesel version would be a 294 CID engine. The displacement reduction is required to maintain similar stresses and bearing loads in the engine, according to Ford. The 294 CID Diesel engine was projected to have a prechamber, operate at 22:1 compression ratio, and develop 130 net BHP at 4000 RPM.

Based on engine mapping of an Opel 2100D, Ford projected that the V-8 Diesel in a 4500 to 5000 pound IW vehicle could achieve 0.41 HC, 3.4 CO, 2.0 NOx with minor changes to injection timing and small amounts of EGR. Smoke was projected to be somewhat higher. Based on engine mapping and computer simulations, the V-8 was projected to be able to achieve 1.0 NOx also, but with higher than statutory HC and CO. The use of oxidation catalysts was not considered in the Ford analysis. Smoke was estimated to be three times higher than on the uncontrolled Diesel V-8. Odor and said to be three times higher than on the uncontrolled V-8. Odor and sulfate emissions were said to be additional problems.

Also based on the engine mapping of the Opel engine, a four cylinder vehicle at 3000 IW was projected to have hot start FTP emissions below 0.41 HC, 3.4 CO, 1.0 NOx with smoke emissions increased by about a factor of three. The vehicle was also projected to be able to achieve 0.41 HC, 3.4 CO, 0.4 NOx on the hot start FTP with smoke emissions about seven times higher than for the standard vehicle.

Fuel economy comparisons of both V-8 and I-4 Diesel engines to their gasoline counterparts were generated by Ford. The results of the computer analysis are shown in Table Ford-17. The baseline V-8 and I-4 were assumed to have 0-60 MPH times of 13 and 15 seconds respectively.

Ford did not reveal a decision on the continuation of Diesel studies. But since little progress has been reported from last year, it could be assumed that Ford will not build a Diesel prototype in the near future.

Stirling

Development of the Stirling engine has progressed to the point where an engine has been installed in a vehicle, but emissions testing has not been conducted at this point in time, according to Ford.

Table Ford-17*

Comparison of Fuel Economy Improvements of the Swirl Chamber Diesel Engine Relative to the Gasoline Engine

	Emission Standard HC/CO/NOx	% Fuel Economy Improvement on Actual Tank Fuel (1)
V-8 Gasoline Engine Base	1.5/15/3.1	-
Equal displacement	0.41/3.4/2.0	26
V-8 Diesel	0.41/3.4/1.0	16
Equal performance	0.41/3.4/2.0	19
V-8 Diesel	0.41/3.4/1.0	10
I-4 Gasoline Engine base	1.5/15/3.1	-
Equal displacement	0.41/3.4/2.0	18
I-4 Diesel	0.41/3.4/1.0	17
Equal performance	0.41/3.4/2.0	6
I-4 Diesel	0.41/3.4/1.0	5

(1) Includes the 11% higher volumetric energy content for Diesel fuels.

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* from Ford Status Report, December 1976, Section IV C, page 6.

7.1.3.2. Systems to be Used at Various Emission Levels

1.5 HC, 15 CO, 2.0 NOx

Future Ford systems for 1.5 HC, 15 CO, 2.0 NOx are much like those used in 1977 Federal certification efforts. The basic systems use EGR and an oxidation catalyst with and without AIR. If these standards are retained for 1978, Ford plans to introduce a new electronic EGR and spark control system on one model that is equipped with the 302 CID engine. Ford also plans to introduce some models with pulse AIR, apparently as a cost saving measure. Minor evaporative emission control system modifications are planned to meet the 6 gm SHED standard.

Ford stated that they should be able to comply with the 18 MPG$_c$ standard in 1978, again assuming 1.5 HC, 15 CO, 2.0 NOx is retained. The cost increase of 7-11 dollars was said to be for revised evaporative systems. The cost increase seems to neglect the possible conversion to pulse AIR, the potential deletion of AIR on some models, and potential reductions in catalyst loading, all of which would tend to reduce emission control system costs.

0.41 HC, 9 CO, 1.5 NOx

Ford systems for this emission level in 1978 on a Federal basis may be very limited, according to Ford. They indicate that the 302 engine family with AIR, EGR, and oxidation catalysts is the only engine which achieves these levels in certification for the 1977 model year. Thus with no additional certification efforts, Ford could sell only about 20% of their planned 1978 production.

Ford indicated that a 12% fuel economy loss would result even if line-crossing and a credit for non-methane hydrocarbons were assumed.

For this standard in California, Ford plans to introduce a 3-way plus oxidation catalyst system in 1978. The system will also include a Holley feedback carburetor, an oxygen sensor, EGR, and AIR on the 2.3 litre engine family. A start catalyst will also be added to the 200 CID, six cylinder engine family to attempt to certify this AIR, EGR, oxidation catalyst family for California.

Though not stated by Ford, this emission level could possibly permit the deletion of both the AIR injection system and the oxidation catalyst of 3-way catalyst systems like the one used on the 2.3 litre engine family for California.

0.41 HC, 3.4 CO, 2.0 NOx

At these emission levels in 1979 and 1980, Ford stated that they will expand the use of 3-way plus oxidation catalyst systems. Feedback carburetion would be used in combination with the use of electronic EGR and spark control on those vehicles. Other models would retain oxidation catalyst systems similar to those of 1977.

The cost of these systems would be $180-$380 more than systems to meet 1.5 HC, 15 CO, 2.0 NOx, according to Ford. This will allow for the use of 3-way plus oxidation catalysts and electronic spark, EGR, and air-fuel control on large cars and feedback carburetion, 3-way plus oxidation catalyst systems on small cars.

0.41 HC, 3.4 CO, 1.0 NOx

The achievement of these standards in 1981 would be accomplished by using all 3-way plus oxidation catalyst systems in combination with electronic EGR and spark control. Vehicles at low inertia weights, such as the Pinto with a 2.3 litre engine for California in 1978, may not require electronic spark or EGR.

Ford stated that the initial cost increase would be $210-$310 over the 1.5 HC, 15 CO, 2.0 NOx systems. This is a smaller cost increase than stated for 0.41 HC, 3.4 CO, 2.0 NOx, but reflects cost reductions due to newer electronic control components and higher volume production rates of the electronic components. According to Ford, the effect on fuel economy would range from minus 6% to minus 1% compared to 1977-1978 Federal systems. The vehicles with poorest fuel economy have the least number of electronic emission control systems.

0.41 HC, 3.4 CO, 0.4 NOx

Ford stated that they have not identified emission control systems with the capability of achieving this emission level. Developmental efforts were reported at this target emission level for two engine families which are currently sold by Ford - the 2.3 litre and 351-W. The vehicle with the 2.3 litre engine (VIN 112T511) did not even come close to low mileage statutory emission goals. The fuel metering system used on this 3-way plus oxidation catalyst system was a recalibrated, open loop carburetor. No testing of the vehicle with the 351-W engine was reported, but the vehicle is to use a more sophisticated air-fuel metering system. The Ford 8-channel EFI system is to be used in conjunction with the 3-way plus oxidation catalyst system.

The vehicle with the 351-W engine, which is being developed under the IIEC-II program and is called a "Concept Car", appears to have incorporated some of Ford's better developmental hardware. This hardware includes EFI, electronic spark control, and electronic EGR control. Since the catalyst selections were not fully described, it is difficult to evaluate the selections except to note that the total catalyst volume may be inadequate for 50,000 miles of durability operation.

7.1.3.3. Durability Testing

Precertification durability testing is currently in progress on both the Pinto with the 2.3 litre with the 3-way plus oxidation catalyst system and the 302 CID, oxidation catalyst vehicle with electronic spark and EGR control for 1978 model year. The reported test results are shown in Tables Ford-18 and Ford-19. The 2.3 litre Pintos show the potential to get as low as 0.41 HC, 3.6 CO, and 1.0 NOx. The design objective for fuel economy was to get 1 MPG better than the 1977 model Pinto for California. Ford indicated that the fuel economy objective is being met. The fuel economy of the comparable 1977 Federal fuel economy vehicle* was 22.9 MPG_u, 32.5-32.8 MPG_h. In comparison, the vehicles with the 3-way catalyst systems show a 2-3% urban fuel economy penalty over the 1977 Federal vehicles. The vehicle with the electronically controlled 302 CID engine shows good capability for 0.9 HC, 9 CO, 2.0 NOx. The last two tests on Table Ford-19 may indicate capability for 0.39 NMHC, 9 CO, 1.5 NOx. Insufficient information was provided on this vehicle to permit a fuel economy comparison to be made.

About 20 vehicles equipped with various electronic emission control systems are either just starting or being prepared for durability testing. Details of the vehicles and emission targets were not given, except that a number of feedback carburetors will be tested and that the NOx objectives are low (probably 1.0 NOx).

The Low NOx Fleet which was reported a year ago has completed durability testing. The fleet consisted of nine vehicles. All vehicles had 302 CID engines and were tested at 3500 pounds IW. Three vehicles used 192 cu in. oxidation catalyst (OC) systems, and six vehicles used 3-way plus oxidation catalyst (3W+OC) systems. The vehicles with the 3W + OC system had 3-way catalysts of 96 cubic inches and an oxidation catalyst

Table Ford-18

2.3 litre Pinto with FBC

Package: Pinto, 3 door, 3,000 lbs IW, 3.18 Axle
Transmission: M-4
Catalyst: 80 CID 3-way plus 80 CID OC

	--------	'75 FTP	--------		
Mileage	**HC**	**CO**	**NOx**	**MPG_u**	**Remarks**
Vehicle # 1					
Sign-Off	0.28	1.97	1.18		
0	0.31	1.90	0.78	19.3	Replaced faulty solenoid
5K	0.24	1.57	0.77	21.3	on FBC
10K	0.47	3.67	0.76	21.6	
15K	0.43	3.36	0.88	21.1	
18K	0.39	2.96	0.59	23.6	Replaced failed EGR
20K	0.39	3.20	0.69	21.8	transducer
25K	0.35	3.04	0.98	23.7	Veh. stalls at idle
30K	0.43	3.50	0.71	22.4	Before maintenance
30K	0.44	3.26	0.58	24.3	After maintenance
35K	0.51	3.12	0.63	23.0	
40K	0.49	2.91	0.69	-	
				22.5 Avg. 5K-40K	
Vehicle # 2					
Sign-Off	0.24	1.75	1.20		
0	0.31	2.04	1.09	20.4	
5K	0.26	2.03	0.62	23.3	
10K	0.43	4.46	0.64	20.5	
12K	0.24	1.58	0.70	21.7	Replaced regulator and
15K	0.29	1.29	0.77	23.1	adjusted ECU
20K	0.41	1.83	0.81	23.5	
				22.1 Avg. 5K-20K	

Table Ford-19

1978 302 CID Vehicle with Electronic EGR and Spark Control

Mileage	'75 FTP HC	'75 FTP CO	'75 FTP NOx	MPG_U	Remarks
Develop. Objective	0.40	6.22	1.32		
56	0.37	4.03	1.74	12.4	"0" Mile Test
6745	0.37	4.95	1.89	14.1	5K Test
9171	0.36	2.80	2.20	14.5	Bef. and Aft. Carburetor
	0.54	3.91	1.97	14.2	Replacement
9872	0.53	6.32	1.89	14.7	10K Tests
	0.44	4.79	2.00	14.6	
15080	0.43	3.49	2.00	14.4	15K Test
19802	0.45	4.12	2.10	14.9	20K Test
20485	0.48	4.57	1.97	14.6	Repaired broken vac. tee
24800	0.47	3.19	2.13	14.3	25K Tests
24824	0.45	4.32	2.37	14.4	
29400	0.75	6.38	4.15	14.7	30K Test
29452	0.63	4.92	3.82	14.8	EGR Valve replaced
29527	0.50	7.08	1.43	14.4	Tests after repair of
	0.53	4.04	1.36	14.0	faulty wiring harness

of 96 cubic inches. The Pt/Rh ratio of 1.5/1 in the 3-way catalysts is very high and may raise questions concerning production feasibility for a large number of vehicles. All nine vehicles used backpressure EGR. All vehicles used open loop carburetion, though the six carburetors for 3W + OC vehicles were carefully flowed before durability mileage accumulation started to provide approximately stoichiometric operation. Additionally, idle CO was periodically adjusted on three of the 3W + OC vehicles to ensure stoichiometric operation over mileage accumulation. The projected 4000 mile and 50,000 mile emissions and deterioration factors of the nine vehicles are shown in Table Ford-20.

Table Ford-20

Low NOx Fleet Vehicles

			Projected 4K			Projected 50K			DF	
VIN	System	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx
1P*	3W + OC	0.29	1.74	0.52	0.38	0.96	0.87	1.33	0.55	1.70
2P*	3W + OC	0.35	1.16	0.74	0.45	1.52	0.62	1.25	1.31	0.83
3P*	3W + OC	0.29	1.11	0.89	0.40	1.72	0.84	1.41	1.56	0.95
4P	OC	0.21	0.85	0.92	0.27	2.29	0.74	1.33	2.69	0.81
5P	OC	0.18	0.72	0.86	0.24	0.96	0.87	1.33	1.33	1.01
6P	OC	0.20	0.74	0.84	0.35	1.71	0.61	1.79	2.31	0.73
7P	3W + OC	0.22	1.20	0.67	0.32	1.63	1.09	1.43	1.36	1.63
8P**	3W + OC	0.29	1.26	0.68	0.43	1.69	0.58	1.51	1.34	0.86
9P	3W + OC	0.34	1.43	0.82	0.34	1.58	1.13	1.00	1.10	1.38

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* idle CO adjusted throughout durability to maintain stoichiometry

** idle CO adjusted only at 25K

Ford also reported the catalyst efficiency results from the vehicles listed in Table Ford-20. These Low NOx Fleet vehicles had their catalyst efficiency determined at the end of the 50,000 mile durability run. The results are shown below in Table Ford-21. The HC and CO conversion efficiencies for all systems show improvements compared to current practice.

Table Ford-21

50,000 Mile FTP Catalyst CO Version Efficiency

VIN	HC	CO	NOx	Remarks
1P	86	92	66	Avg. 4 tests
2P	87	94	69	Avg. 4 tests
3P	85	92	66	Avg. 4 tests
4P	77	91	5	Avg. 3 tests
5P	85	95	-2	Avg. 3 tests
6P	83	95	3	Avg. 4 tests
7P	92	87	57	Avg. 4 tests
8P	85	91	62	Avg. 3 tests
9P	90	91	65	Avg. 3 tests

These results suggest that Ford could certify the 302 CID engine at 0.41 HC, 3.4 CO, 1.0 NOx with either a 3W + OC system or an OC system. A fuel economy differential at low mileage (about 4 MPG_c) between the two systems on deveopmental vehicles (not low NOx fleet vehicles) suggests that the 3W + OC system is the logical choice for production as shown in Table Ford-22.

Table Ford-22

4,000 or 5,000 Mile Fuel Economy

Vehicle	MPG_u	MPG_h	MPG_c
Developmental 3W + OC	15.0	22.4	17.5
Developmental OC	11.5	17.0	13.5
'77 Federal fuel economy/data cars*	15.4-17.0	18.6-22.1	16.7-19.0

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* 7K1-302-F-35 and 7F1-302-F-33

The urban fuel economy data in Table Ford-23 show that the fuel economy differential between 3W + OC and OC systems at 1.0 NOx was also found in the Low NOx Fleet. The fuel economy of the 3W + OC vehicles in Table Ford-23 are within the fuel economy range of the similar 1977 Federal vehicles in Table Ford-22.

7.1.3.4. Progress and Problem Areas

Ford has made significant progress on individual emission control components in the past year. Their program for development of feedback carburetors has been relatively successful, at least at low mileage. The development of a first generation of individual and combined electronic emission control components is now complete, and the development of a second generation of electronic emission control components is progressing. Their durability testing has shown the 3-way plus oxidation catalyst system to be capable of control to 0.41 HC, 3.4 CO, 1.0 NOx with little impact on fuel economy. The fuel economy performance could have possibly been even better had the vehicles used the electronic subsystems that Ford has under development. Screening of 3-way catalysts has yielded a number of catalysts which appear to merit durability testing on vehicles. The M-257 catalyst, shown in Figure Ford-7, appears especially promising.

The major problems for Ford seem to be: 1) to apply advanced emission control components, such as combined, electronic control of spark, EGR, and air-fuel metering and 3-way plus oxidation catalysts, to all engine families and 2) to establish the durability of these combined systems. While component development programs have been successful, durability testing of combined systems is just beginning.

Ford stated their major problems to be: 1) experience with component durability, 2) sufficient lead time to gain field experience with new components and to permit an orderly introduction of new components on

Table Ford-23

Low NOx Fleet Fuel Economy
Low and High Mileage Results

VIN	System	5K MPG$_u$ Range	5K-50K MPG$_u$ Range	Mean MPG$_u$* (5K-50K)
1P	3W + OC	13.4 - 14.7	13.9 - 17.1	15.8
2P	3W + OC	16.2 - 16.3	14.9 - 16.6	15.8
3P	3W + OC	15.9 - 16.3	15.2 - 16.9	15.9
4P	OC	10.9 - 11.1	10.5 - 12.3	11.3
5P	OC	11.1 - 12.0	11.1 - 12.3	11.7
6P	OC	11.8 - 12.0	10.5 - 12.1	11.3
7P	3W + OC	14.8 - 15.8	14.8 - 17.1	15.9
8P	3W + OC	15.5	14.8 - 17.0	16.1
9P	3W + OC	15.6 - 16.1	14.8 - 16.6	15.7

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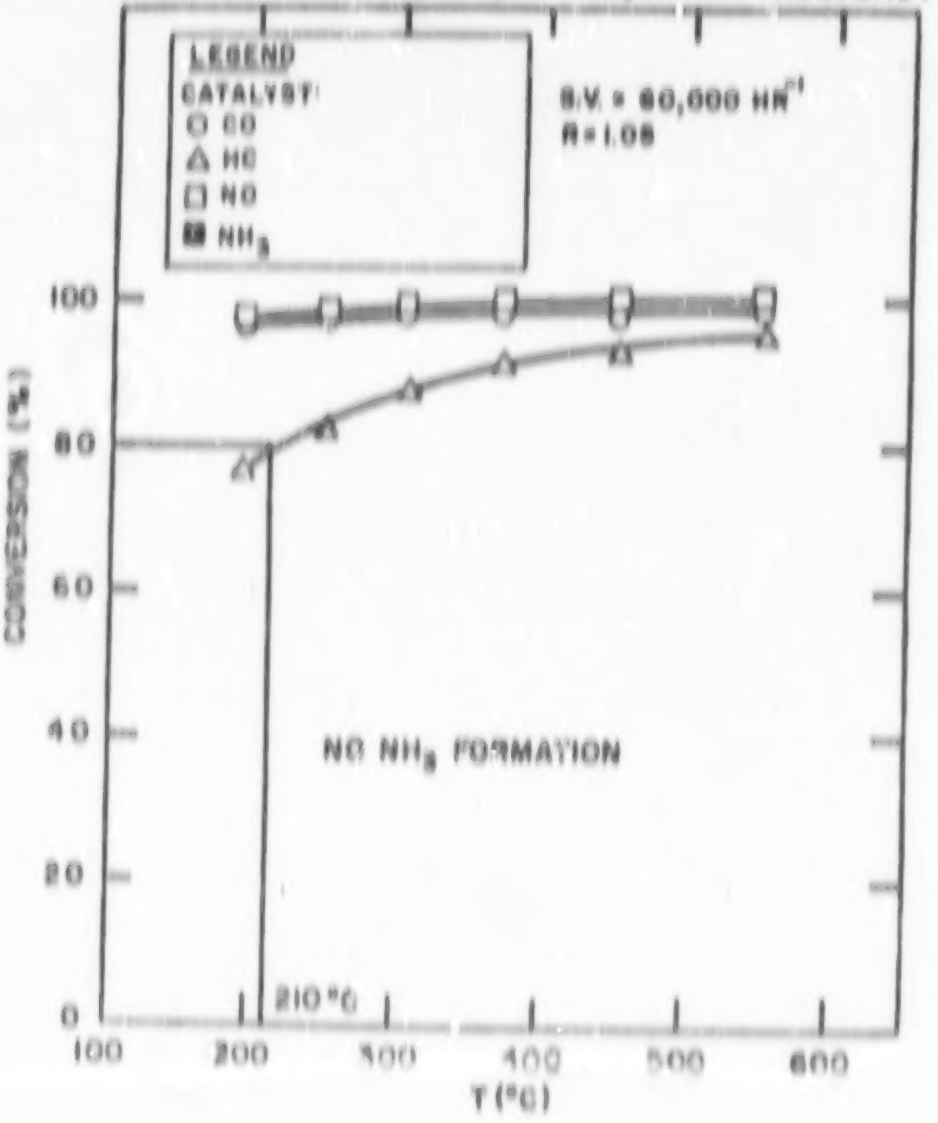
* Number of tests at individual mileage points are not equal, mean includes all test points.

Figure Ford-7

TEMP EFFECT ON CONVERSION OF NO, CO, HC OVER M-257 CATALYST

PRETREATMENT: 100 HOURS AT 1500 °F WITH MODULATIONS OF (1% O_2/2% CO) AT 6Hz FREQUENCY



the various engine families, 3) the potential deletion of manual transmissions for 200 CID and larger engine families if 0.41 HC, 3.4 CO, 2.0 NOx is required in 1979, 4) the achievement of 1981 and subsequent model year fuel economy standards along with 0.41 HC, 3.4 CO, 1.0 NOx emission standards, and 5) the lack of demonstrated capability to control emissions to 0.41 HC, 3.4 CO, 0.4 NOx for 50,000 miles.

The component durability issue is now being resolved with testing on the two vehicles with the 2.3 litre engine, the vehicle with the 302 CID engine, and the twenty vehicle fleet. It is not known why the twenty vehicles are just now being prepared for durability since all key components seem to have been ready for some time, with the possible exception of feedback carburetion. It appears that Ford may have been waiting for the further development of feedback carburetion before starting durability testing. Other, possibly more costly, fuel metering systems may have been the only ones available earlier.

Since Ford has expended considerable effort on systems with potential for low NOx emissions and high fuel economy, such as 3-way catalyst systems, the PROCO, and the CVCC, Ford may have highly efficient engines available for the 1981 and subsequent model years. Ford's plans for vehicle weight reduction and engine availability have not been released so their ability to comply with future fuel economy regulations (which are as yet undetermined for the 1981-84 time frame) cannot be accurately determined.

The "Concept Car" is now being built by Ford as a participant of the Inter-Industry Emission Control Program. The goal for the "Concept Car" is to demonstrate the 0.41 HC, 3.4 CO, 0.4 NOx emission levels. If the program is successful, another problem for Ford will be alleviated.

7.1.4. General Motors

7.1.4.1. Systems Under Development

The General Motors (GM) systems under development for model year 1978 and post-78 years range from those systems presently used on the 1977 model year vehicles to basic research on potential emission control hardware. The descriptions of the potential GM systems are described below. Since GM "...anticipated that 1978 emission standards would be carry over 1977 standards..."* the bulk of GM's work has concentrated on improving the system life and fuel economy of the 1977 model year system consisting of an oxidation catalyst, exhaust gas recirculation (EGR), ignition timing, and carburetor calibrations. The evaporative emission control system will be modified by routing fuel vapors from the carburetor bowl to the evaporative emissions canister during vehicle shut down. For California, GM plans to meet carryover standards of 0.41 HC, 9 CO, 1.5 NO_x. Emission control systems to meet these standards would be similar to 1977 California systems, consisting of an oxidation catalyst, back pressure EGR, air injection by AIR or PULSAIR, and improved carburetion. GM may introduce in California a limited production of vehicles using closed-loop 3-way catalyst systems targeted to meet standards of 0.41 HC, 9 CO, 1.5 NO_x. GM is also planning to introduce a turbocharged Buick V-6 engine and a 350 CID light duty Diesel engine.

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* GM Advanced Emission Control System Development Progress, December 15, 1976, p. VII-1.

GM's estimates of potential system hardware and fuel economy at various emission standards are given in Table GM-1.

Oxidation Catalysts

GM continues to evaluate catalyst samples submitted from approximately 25 catalyst suppliers. This testing includes both engine dynamometer and vehicle tests in addition to catalyst activity and physical property testing. GM also has been conducting evaluations for improving oxidation catalyst system performance and durability. A five car test fleet was assembled using four catalysts that appeared promising based on bench test results. These catalysts are to be compared to the present production GM catalysts. Catalysts were rotated between vehicles and after 25,000 miles none of the test catalysts appear superior to the present production catalyst, according to GM, but they are continuing the testing. GM has continued to place emphasis on improving catalyst light-off. One method tried was reduction of converter metal cross-sections which did not prove successful. Use of small monolithic catalysts installed in the engine exhausts ports proved to be of no advantage for emission reduction, according to GM.

Work on reducing the effects of fuel and oil constituents on catalyst durability was unsuccessful in reducing emission levels as was a study using an experimental 367 cu in. catalyst in place of the production 260 cu in. pelleted catalyst.

Some interesting work is being conducted by GM on monolithic catalysts, and lower density pelleted catalyst (approximately 30 lbs/cu ft.). This work is investigating potential replacements for the conventional underfloor, pelleted catalyst. Table GM-2 gives the zero mile tests results for two types of pelleted catalysts versus a monolithic catalyst.

Table GM-1

Emission Standards and Fuel Economy

Year	Standards			Potential System Hardware	Fuel Economy Losses		Remarks
	HC	CO	NOx		Percent	MPG (18.6 MPG Base)	
1977	1.5	15	2.0	Oxid. Converter, EGR	Baseline	18.6[1]	Includes a 5% fuel economy loss from 1976 standards (1.5, 15, 3.1).
1980-81	0.9	9	2.0	Oxid. Converter, AIR, EGR	0	18.6	Lead time requirements would prevent AIR and BPEGR usage in 1978.
1982	0.41	3.4	2.0	Oxid. Converter, AIR, EGR	10-20	14.7-16.6	Further improved catalyst system performance and durability for 1978 and later years may reduce penalty to lower end of range shown. Current systems show penalties up to 20%.
1977	0.41	9	1.5	Oxid. Converter, AIR, EGR	11[2]	16.4	Limited product availability.
	0.41	3.4	1.0	Large Engine/Small Car, Oxid. Converter AIR, EGR	15-30	12.9-15.8	Larger engines and higher axle ratios reduce NOx emissions by reducing engine load.
				3-way converter C/L, EGR	0-20	14.7-18.6	The fuel economy losses may be at the lower end of the range only if satisfactory catalyst durability can be developed and an adequate supply of catalyst material is available. To date, no system has been developed that meets EPA emission test requirements for 50,000 miles with reasonable maintenance requirements.
				Dual Converter U/L, AIR, EGR	10-20	14.7-16.6	
1978	0.41	3.4	0.4	Same catalyst system selections as 0.41, 3.4, 1.0 stds.	10-30?	13.0-16.6	Meaningful assessment of fuel economy penalty cannot be made since control systems have not been demonstrated to meet statutory standards through the complete certification process including the 50K mile durability requirements.

(1) EPA calculation of 1977 GM fleet average based on Part I Certification sales forecasts.

(2) Loss would be more than 11% if California's methane allowance, audit requirements, and carry across of Federal durability data were not permitted.

Note: Diesel engines are not included.

Table GM-2

Zero Mile Testing of the Effects of Converter Type on Emissions and Time for Exhaust Exiting Converter to Reach 600°F

Converter Type	FTP Emissions--gm/mi HC	CO	NOx	Time to Reach 600°F--seconds
260 cu in. Pelleted (GM Prod.)	0.35	3.11	1.40	338
160 cu in. Pelleted (GM Prod.)	0.37	2.82	1.44	224
150 cu in. Monolithic (Competitive Product)	0.24	2.11	1.45	165

As can be seen from Table GM-2, the monolith, even though it is 42% smaller than GM's 260 cu in. pelleted catalyst, had improved light-off and emission performance, at zero miles. If one considers the 160 cu in. pellet to be roughly the same volume as the 150 cu in. monolith, emission improvement factors of 0.65 for HC, 0.75 for CO, and 1.01 for NOx are indicated. Applying these factors to the 260 cu in. pelleted catalyst results indicates that 0.23 HC, 2.33 CO, 1.41 NOx might be predicted for a monolithic catalyst of approximately the same volume as GM's 260 cu in. pelleted catalyst, based on Table GM-2.

Three durability vehicles using the monolithic converters can be found in Table GM-24. A 43 vehicle customer service fleet is being assembled to evaluate monolithic catalysts under field use conditions.

Hybrid monolith-pelleted converters (40 cu in. monolith plus 180 cu in. pelleted), and a system using a catalytically-action cloth made by Mitsubishi over the pellets in a 260 cu in. container were also evaluated. No further work is planned for these concepts.

GM continues to investigate the expanded use of the start catalyst introduced in 1977 on the L-6 engines in California. Reference was also made to a 48 vehicle test fleet for a close coupled catalyst on the "X" car which may be a monolith and radial flow pellet design.

GM has continued research into identifying ways in which the loss of catalyst activity can occur. Catalyst poisoning by lead and phosphorus and noble metal sintering are recognized as the two principal modes of catalyst deactivation. The studies of noble metal sintering has led GM to conclude that:

-FTP HC emissions were nearly doubled as a result of sintering of the platinum catalysts. CO emissions increase by 50% to 300% depending upon the converter volume tested. The palladium catalyst was much more resistant to sintering, resulting in HC and CO emission increases of about 25%.

-Nearly all of the increase in CO emissions was caused by decreased noble metal surface area. Once warmed-up, the sintered catalysts showed remarkably high CO conversion efficiencies (> 90%).

-Sintering reduced the HC activity of both the platinum and palladium catalysts throughout the FTP, with increased HC emissions occurring in both cold and hot cycles.

-The HC and CO emissions suggest that noble metal surface area influences oxidation only during those periods of catalyst operation when reaction kinetics control the overall rate of oxidation. After the catalyst is fully warmed-up, the CO oxidation rate becomes mass transfer limited and is no longer controlled by catalyst metal surface area. HC oxidation, on the hand, is not completely limited by mass transfer even when the catalyst is fully warmed-up. Considering the great variety of HC species present in engine exhaust gases, it is reasonable to suppose that oxidation of some species is mass transfer limited, while the more oxidation resistant HC species remain kinetically limited. Thus, overall HC oxidation continues to be influenced by noble metal surface area in the hot FTP cycles.

GM investigated methods of rejuvenating alumina supported platinum-palladium catalysts with dilute solutions of ammonium oxalate. The results indicated a partial removal of lead compounds from poisoned catalysts, with less effectiveness in regenerating catalysts poisoned by a combination of lead and phosphorus, and no effectiveness in regenerating catalysts deactivated by noble metal sintering.

GM also presented data which indicated that the phosphorus in engine oils has a potentially detrimental effect on catalyst HC conversion efficiency.

3-Way Catalysts

At the statutory emission levels, GM maintains that some emission control systems incorporating a catalytic control of NOx will be necessary. GM is presently running development vehicles using systems containing: (1) platinum/rhodium 3-way catalysts (0.01-0.02 troy ounces of rhodium), (2) three-way closed loop catalysts, (3) 3-way plus an oxidation catalyst, (4) reactor plus a 3-way catalysts, and (4) a reactor-reduction catalyst-reactor system. The latter concepts will be discussed later.

GM has maintained that because of limited rhodium availability, the use of catalysts with high rhodium loadings will not be production feasible.

GM utilizes a closed loop fuel metering system, both carbureted and fuel injected, to maintain stoichiometric or slightly rich air-fuel mixtures in the 3-way catalyst systems. Details of the fuel metering systems were generally not provided by GM.

However, it was revealed in the automotive industry press* that GM is planning to revamp two carburetion systems for 1978, the Varajet and Dualjet. The relationship to the needed fuel metering control for 3-way catalyst and these carburetors is unclear.

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* Ward's Engine Update, 4 February 1977, page 1.

GM is apparently planning significant changes in fuel metering within the next few years. GM's targets are to make it possible to introduce a closed loop system on all GM light duty vehicles for start of production, 1980, with a limited sample for California for start of production 1978. Timing charts for these two programs are shown in Figures GM-1 and GM-2. Closed loop carburetors (Quadrajet, Varajet, Dualjet, Holley Staged 2bbl) as well as single and dual point fuel injection are being considered.

The results of the development vehicles can be found in Table GM-3 while the durability vehicle results can be found in Table GM-24. The two 3-way catalyst durability vehicles, 65375 and 64384, are described in the durability vehicle sections.

The development of vehicle 66312A was an attempt to use a 3-way catalyst without EGR. Vehicle testing has been terminated.

These data comprise the total 3-way catalyst development vehicle work reported by GM. Work continues on evaluating potential 3-way catalysts using bench and engine dynamometers.

3-Way Catalyst Plus Oxidation Catalyst Systems

GM reported only one vehicle which had a three-way plus oxidation catalyst system. This vehicle (No. 66313, Nova, 305 CID) was equipped with a closed loop 4-barrel carburetor, a production underfloor oxidizing catalyst with programmed air injection, an O_2 sensor, and two 3-way monolithic catalysts mounted in the exhaust down pipes. No details were provided concerning the programmed air injection. The 3-way catalyst is a high platinum-low to medium rhodium Englehard catalyst. The vehicle is presently on mileage accumulation and the low mileage results can be found in Table GM-4. A system schematic can be found in Figure GM-3.

Figure 2A-1 1980 CLOSED LOOP EMISSION SYSTEM SCHEDULE

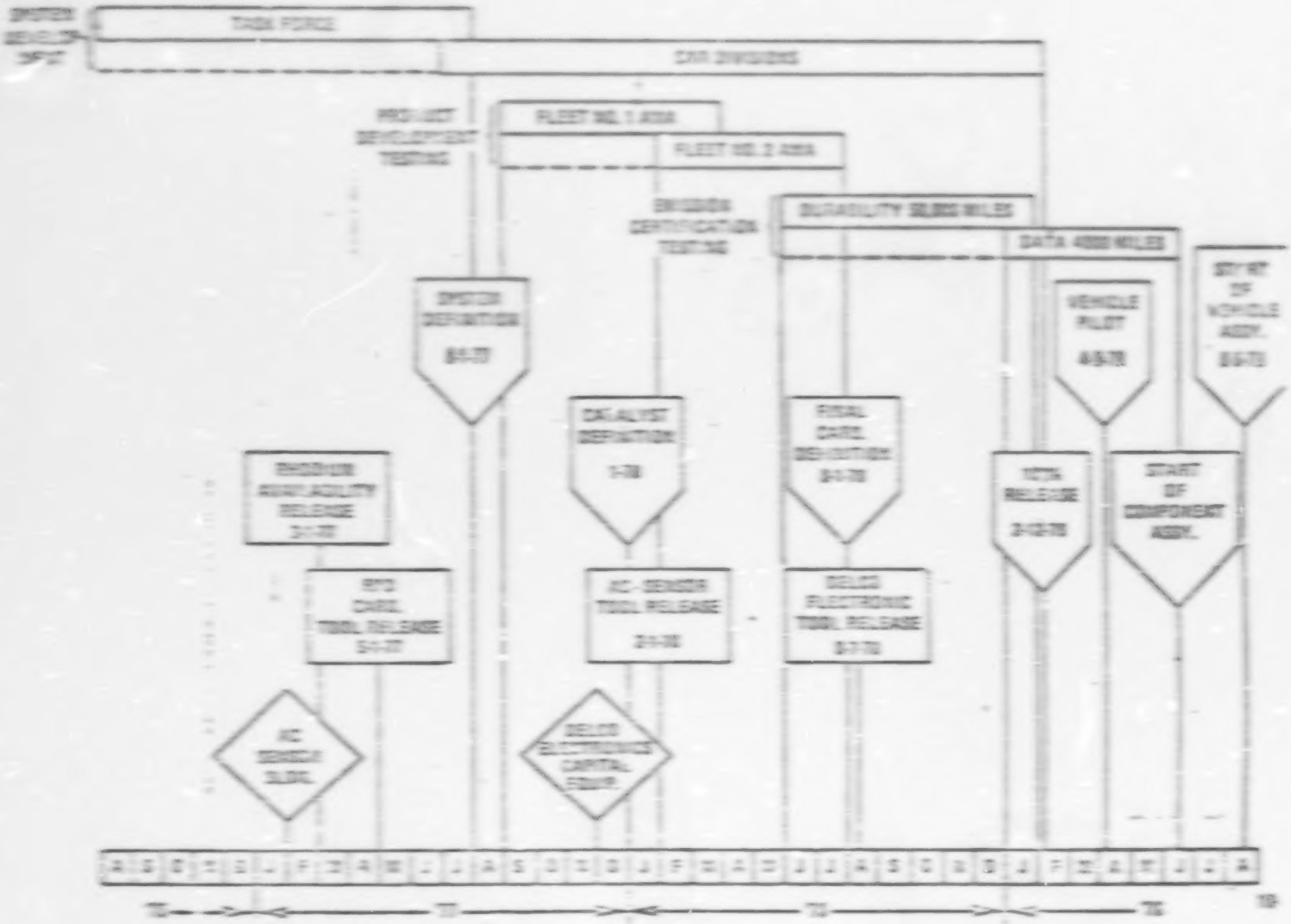
SYSTEM DEVELOP. INPUT
TASK FORCE
CAR DIVISIONS
PROJECT DEVELOPMENT TESTING
FLEET NO. 1 AREA
FLEET NO. 2 AREA
EMISSION CERTIFICATION TESTING
DURABILITY 50,000 MILES
DATA 4000 MILES
SYSTEM DEFINITION 8-1-77
EMISSION ADAPTABILITY RELEASE 3-1-77
RTD CARB. TOOL RELEASE 5-1-77
AC SENSOR BLDG.
CATALYST DEFINITION 1-78
AC-SENSOR TOOL RELEASE 3-1-78
DELCO ELECTRONICS CAPITAL EQUIP.
FINAL CARB. DEFINITION 3-1-78
DELCO ELECTRONIC TOOL RELEASE 3-7-78
RELEASE
VEHICLE PILOT 4-9-79
START OF COMPONENT ASSY.
START OF VEHICLE ASSY.
A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A
76 77 78 79
19

Figure 08-2 TIMING CHART

1978 CALIFORNIA "H" CAR CLOSED LOOP EMISSION CONTROL PROGRAM

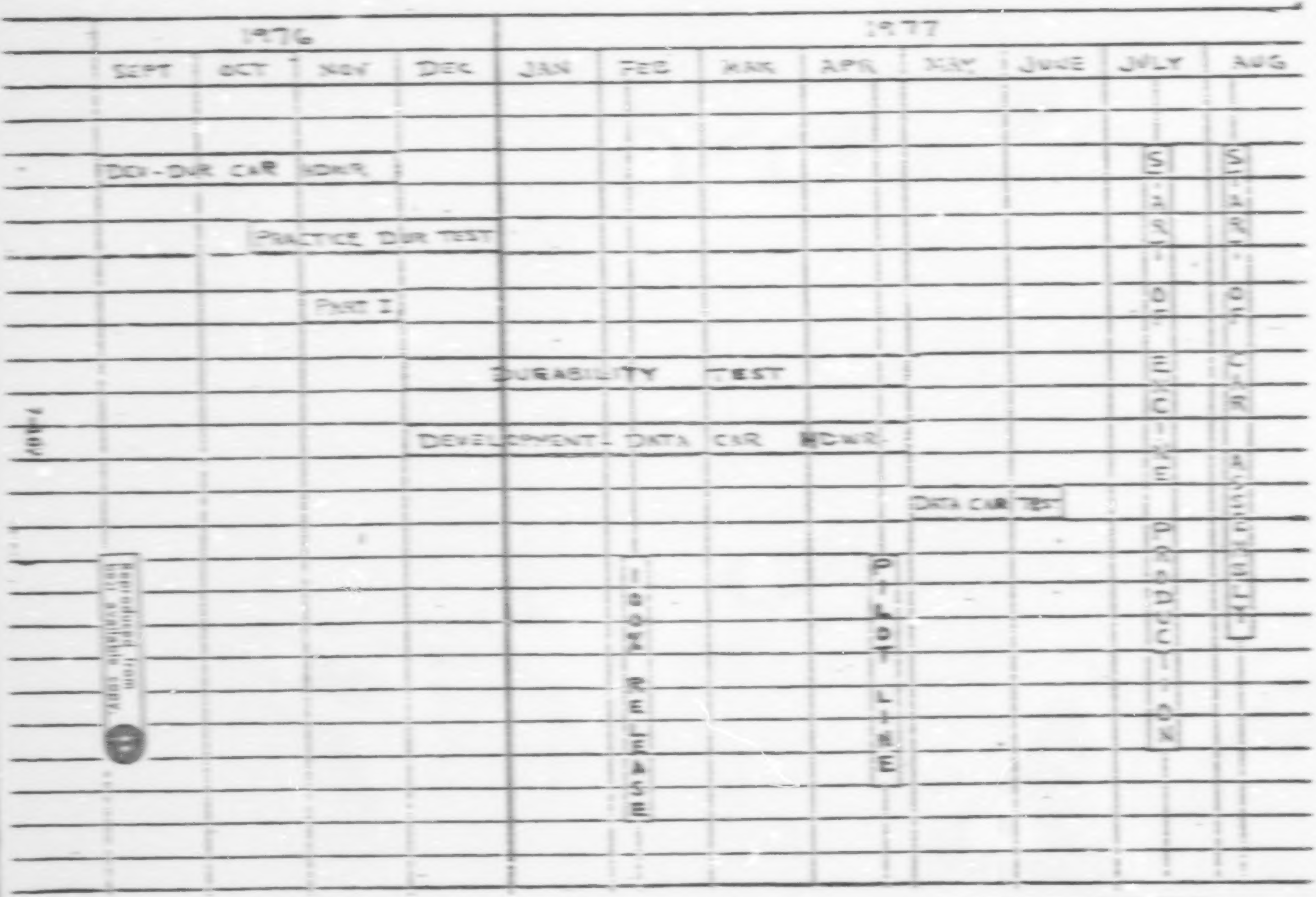

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Table GM-3

GM DEVELOPMENT 3-WAY CATALYST VEHICLES

VIN	Model	CID	Control Sys.	Mileage (10^3)	FTP Results (gm/mi)			Fuel Economy
					HC	CO	NOx	MPG_u
66312	Vega	2.3 litre	BPEGR, 3-way EFI, O_2 sensor EFC*, **	0	0.24	2.70	0.22	18.2
66344	Vega	2.3 litre	Same as 66312, ***	0	0.28	1.69	0.23	18.9
66334	Vega	2.3 litre	Same as 66312 & 66344, Will use 100 cu in. Engelhard monolith for durability accumulation	0	0.35	2.89	0.29	18.9
66312A	Vega	2.3 litre	EFI, O_2 sensor EFC, 3-way No EGR	0	0.25	2.57	0.70	19.6
			Rich bias	0	0.22	4.10	0.36	19.6
(Terminated vehicle)								
66365	Vega	2.3 litre	BPEGR, 3-way Single pt. EFI, Closed loop A/F Electronic Controller, Insulated Exhaust, O_2 sensor	0	0.44	10.[illegible]	0.26	19.3
66315	Chevelle 350		BPEGR, 3-way,	0	0.29	2.81	0.30	12.9
			Closed loop 4 bbl,	5	0.30	4.66	0.27	14.5
			O_2 sensor	12	0.30	5.18	0.26	14.0
66352	Nova H/B 350		Same as 66315 except with low load pelleted Grace catalyst	0	0.29	3.41	0.44	13.0

---

* Electronic Feedback Control (EFC)
** To evaluate the effect of MMT on catalyst and O_2 sensor durability
*** Ashless oil and '77 CO fuel to be used

Table GM-3 (cont.)

VIN	Model	CID	Control Sys.	Mileage (10^3)	FTP Results (gm/mi)			Fuel Economy
					HC	CO	NOx	MPG_u
66201	Seville	350	EFI, BPEGR, O_2 Sensor, Closed loop A/F and Idle Speed control, programable EGR (targeted at higher NOx standards)	0	0.25	1.9	1.0	13.2
60291	Chevette	1.6 litre	PEGR, Pulsair 3-way, air bleed closed loop plus cold spark advance retard	0	0.17	2.67	0.30	24.0
60358	Chevette	1.6 litre	Same as 60291 except with manual transmission	0	0.23	3.05	0.41	26.4

Figure GM-3

THREE-WAY PLUS OXIDATION

CATALYST SYSTEM

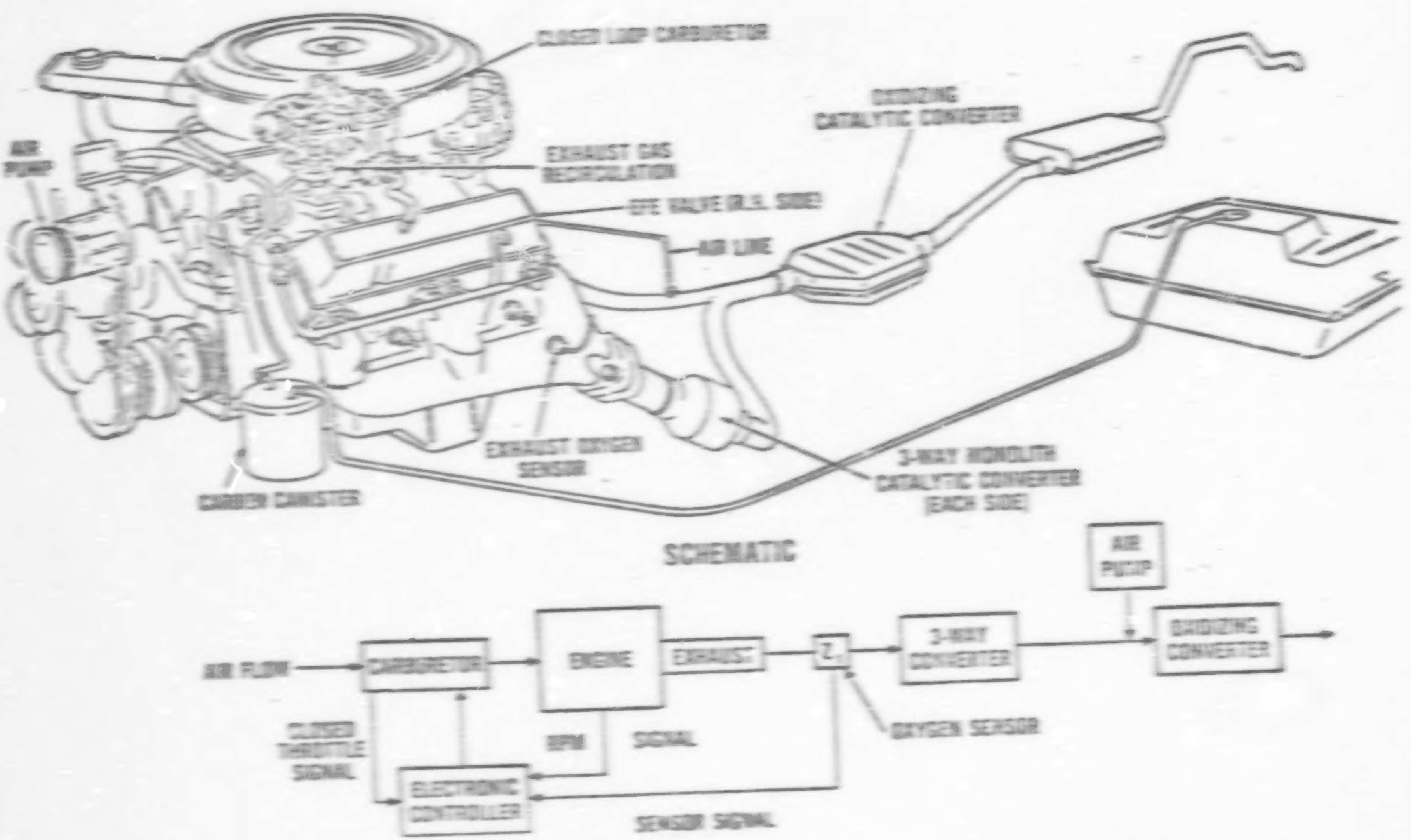

CLOSED LOOP CARBURETOR
AIR PUMP
EXHAUST GAS RECIRCULATION
EFE VALVE (R.H. SIDE)
AIR LINE
OXIDIZING CATALYTIC CONVERTER
EXHAUST OXYGEN SENSOR
CARBON CANISTER
3-WAY MONOLITH CATALYTIC CONVERTER (EACH SIDE)
SCHEMATIC
AIR PUMP
AIR FLOW
CARBURETOR
ENGINE
EXHAUST
Z_1
3-WAY CONVERTER
OXIDIZING CONVERTER
OXYGEN SENSOR
CLOSED THROTTLE SIGNAL
RPM
SIGNAL
ELECTRONIC CONTROLLER
SENSOR SIGNAL

Table GM-4

3-Way Plus Oxidation Catalyst
Car 66313

Mileage (10^3)	HC	CO	NOx	MPG_U	Remarks
0	0.19	1.33	0.43	13.0	
5	0.23	2.47	0.47	13.3	
10	0.30	3.08	0.53	13.3	
15	0.27	2.67	0.74	13.1	
15	0.20	1.89	0.63	12.4	New Design Carb. and Controller
20	0.24	3.02	0.59	13.0	

Dual Catalyst Systems

GM presented data from three dual catalyst vehicles. One vehicle is a Vega (Car No. 66333) equipped with a 140 cubic inch (2.3 litre) fuel injected engine. An exhaust gas oxygen sensor and closed loop fuel controls are used to maintain the air-fuel ratio close to stoichiometric. As shown in the schematic of Figure GM-4, the catalyst system consists of a GM low rhodium loading monolithic reducing catalyst in series with a production pelleted oxidizing catalyst. Air injection is also used on this vehicle. The results achieved with low mileage catalysts on this system are 0.27 HC, 2.02 CO, 0.66 NOx and 16.8 MPG_U. Development is continuing to improve the NOx emissions.

The second vehicle is a Chevelle (Car No. 66346) equipped with a 350 cubic inch engine and a closed loop 4-barrel carburetor. International Nickel Co. base metal reducing catalysts are used in the exhaust down-pipes along with a production underfloor oxidizing catalyst and air injection. Insulated exhaust manifolds and port liners are used to maintain higher exhaust gas temperatures into the reducing converters.

The emission results out to 10,000 miles are shown in Table GM-5. The base metal reducing catalysts were melted and have been returned to the vendor for analysis.

Figure GM-4

DUAL CONVERTER SYSTEM
(Rhodium - Air - Platinum / Palladium)
CLOSED LOOP EFI VEGA

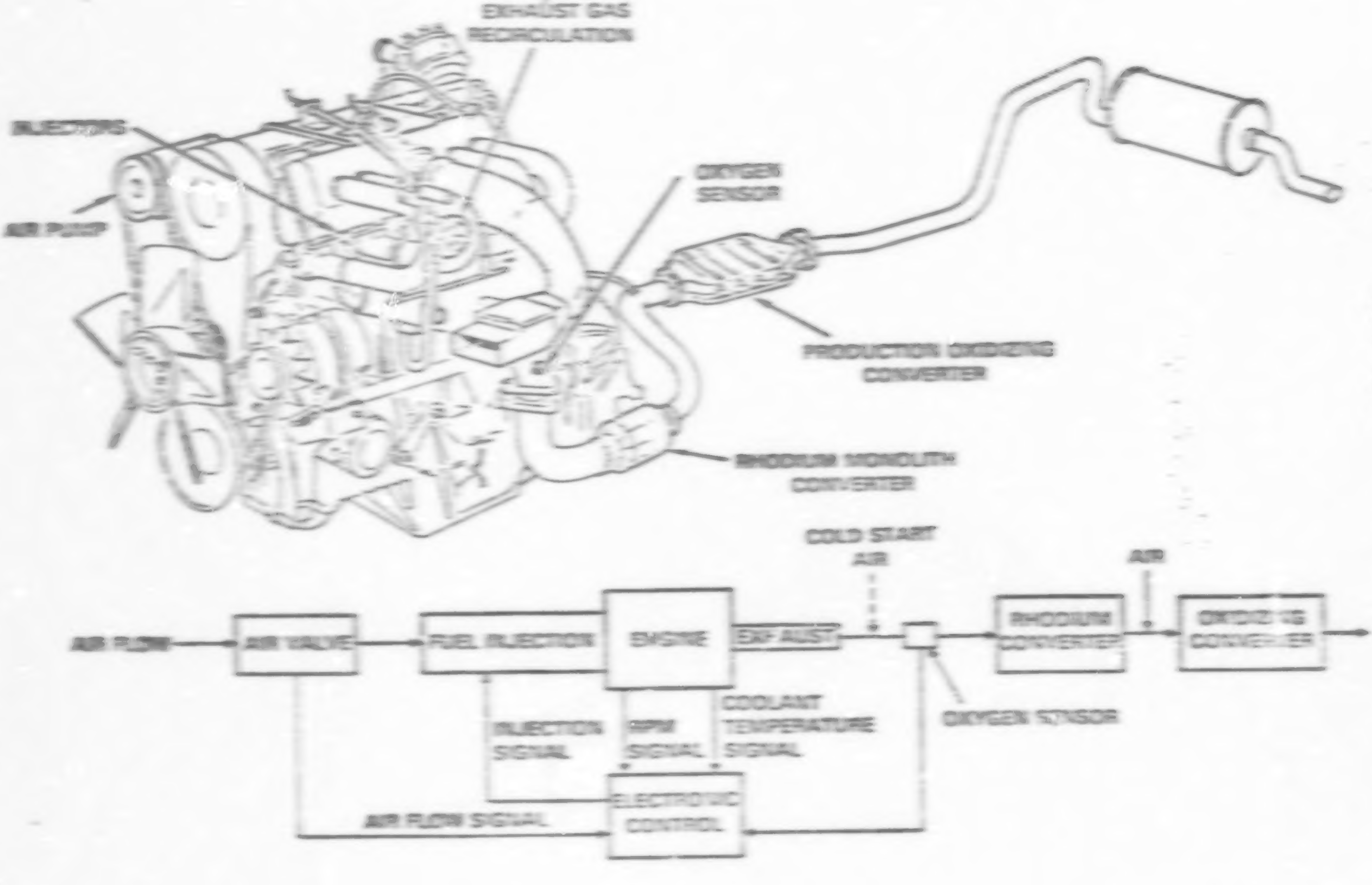

EXHAUST GAS RECIRCULATION
INJECTORS
AIR PUMP
OXYGEN SENSOR
PRODUCTION OXIDIZING CONVERTER
RHODIUM MONOLITH CONVERTER
COLD START AIR
AIR
AIR FLOW
AIR VALVE
FUEL INJECTION
ENGINE
EXHAUST
RHODIUM CONVERTER
OXIDIZING CONVERTER
OXYGEN SENSOR
INJECTION SIGNAL
RPM SIGNAL
COOLANT TEMPERATURE SIGNAL
ELECTRONIC CONTROL
AIR FLOW SIGNAL

Table GM-5

Dual Catalyst Results
Car No. 66346

Mileage (10^3)	HC	CO	NOx	MPG_u	Remarks
0	0.29	1.38	0.36	12.0	
5	0.39	2.73	0.54	12.4	
10	0.52	5.26	0.98	12.0	Recal. Reg.

The third vehicle (Car No. 66340A) is a Chevelle equipped with a 350 cubic inch engine and closed loop 4-barrel carburetor. Reducing catalysts are installed in the exhaust downpipes with an underfloor production oxidizing catalyst and air injection. Insulated exhaust manifolds and port liners are currently used to maintain high exhaust gas temperatures into the reducing catalysts.

Zero mile emission results with a high platinum-high ruthenium loading Dupont perovskite catalyst were 0.48 HC, 1.77 CO, 0.32 NOx, 12.0 MPG_u. Additional tailoring will be performed to optimize conditions for this catalyst. Plans are to screen various other catalysts in this car, to investigate precious metal loadings and catalyst activity. This screening will include a low platinum-medium ruthenium Gulf submission. All previous catalyst submissions from Gulf have contained extremely high amounts of ruthenium, according to GM. The best candidate will start durability testing.

Reactor Plus Converter Plus Reactor System

The reactor/converter/reactor system is another approach that employs a NOx catalyst. This system has three reaction zones. The first zone is a high temperature manifold reactor in which partial oxidation of HC and CO is accomplished. The overall air-fuel ratio out of the first zone remains net reducing so oxides of nitrogen can be reduced in the second zone which utilizes a metallic NOx catalyst. Additional air is injected into the third zone which is another high temperature reactor used to continue the oxidation of HC and CO. In the past year, a reactor/converter/reactor system incorporating closed loop electronically controlled fuel injection, proportional AIR, and BPECR has been designed and fabricated. Initial calibration testing is commencing. This type of system is similar to the system developed by Questor. GM has proposed a new joint limited development test program which Questor is presently reviewing.

Other Development Efforts

Reactor Plus 3-Way Catalyst Systems

GM gave details concerning their work on systems utilizing reactors and various 3-way catalysts. Table GM-6 gives the results of one vehicle (66324) which was used to evaluate not only the reactor plus 3-way catalyst system, but also to evaluate various 3-way catalysts. Figure GM-5 presents a schematic of this system. The other vehicle (66404) used smaller volume manifold reactors plus an Engelhard pelleted catalyst. This vehicle also will eventually be used to evaluate different 3-way catalysts. The only details given on the Oldsmobile Twin Point EFI are shown in Figure GM-6.

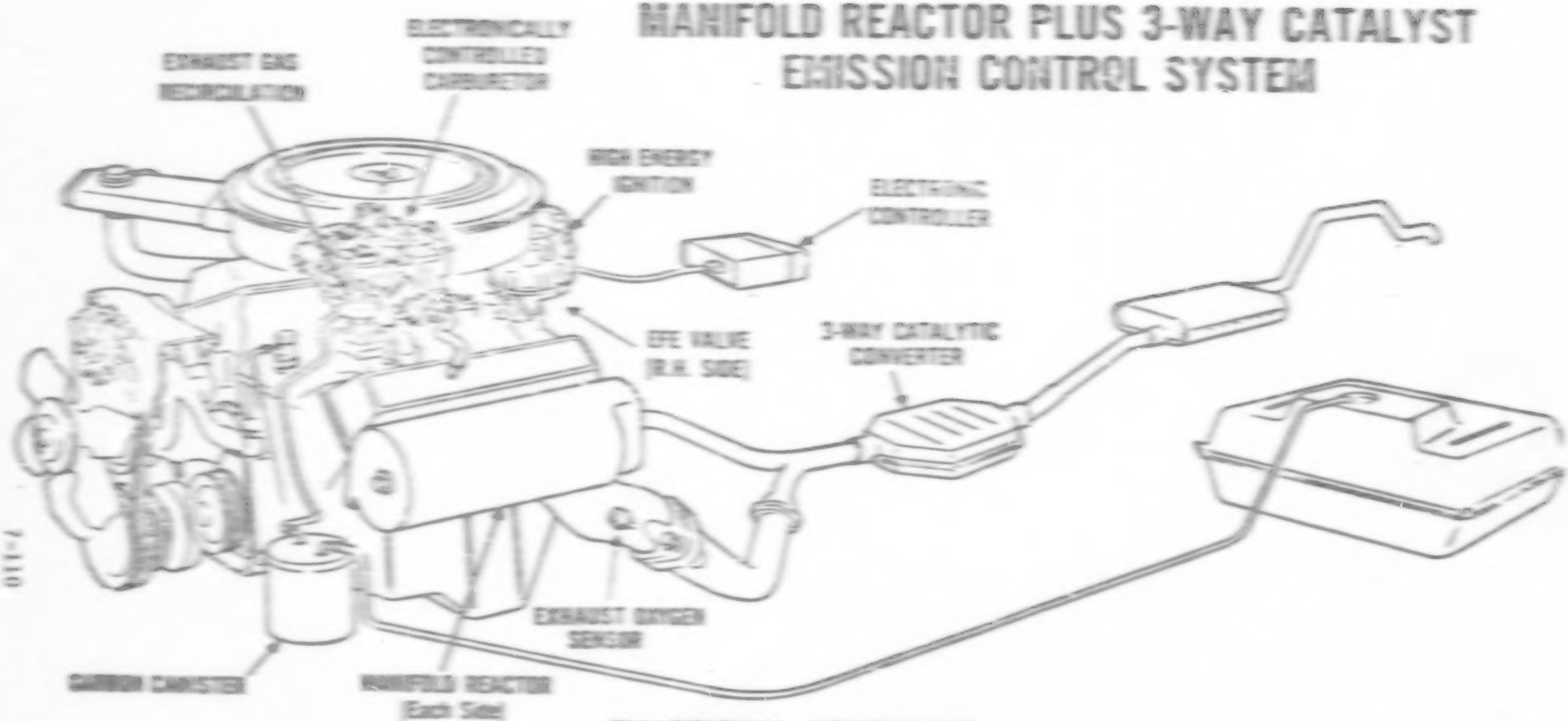
Table GM-6

Reactor Plus 3-Way Catalyst Development Vehicles

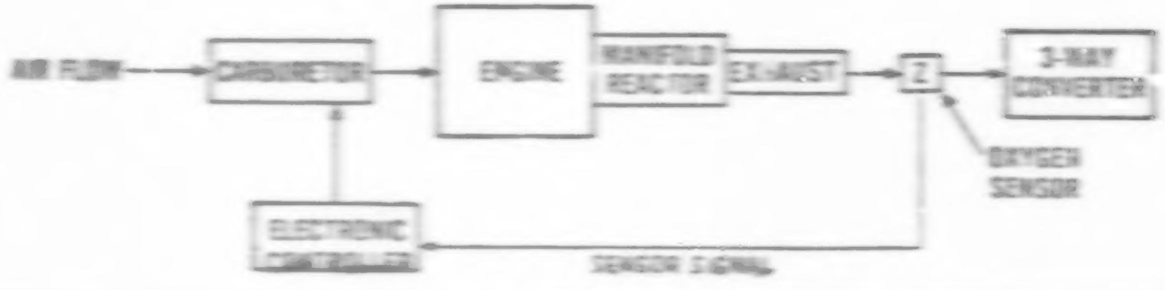
VIN	Model	CID	Mileage	HC	CO	NOx	MPG$_U$	Remarks
66324	Chevelle	350	0	0.22	3.06	0.29	12.4	HN 2217
				0.23	3.56	0.31	13.3	HN 3032
				0.21	3.59	0.37	13.0	HN 3095
				0.21	4.97	0.21	12.8	HN 3096
66404	Cutlass	350	0	0.13	8.50	0.26	12.2	Twin Point EFI, Doubled walled cross-over pipe.

Figure GM-5

MANIFOLD REACTOR PLUS 3-WAY CATALYST EMISSION CONTROL SYSTEM


EXHAUST GAS RECIRCULATION
ELECTRONICALLY CONTROLLED CARBURETOR
HIGH ENERGY IGNITION
ELECTRONIC CONTROLLER
EFE VALVE (R.H. SIDE)
3-WAY CATALYTIC CONVERTER
EXHAUST OXYGEN SENSOR
CARBON CANISTER
MANIFOLD REACTOR (Each Side)

FUNCTIONAL SCHEMATIC


AIR FLOW
CARBURETOR
ENGINE
MANIFOLD REACTOR
EXHAUST
Z
3-WAY CONVERTER
OXYGEN SENSOR
ELECTRONIC CONTROLLER
SENSOR SIGNAL

OLDSMOBILE CLOSED LOOP
STOICHIOMETRIC TWIN POINT FUEL INJECTION

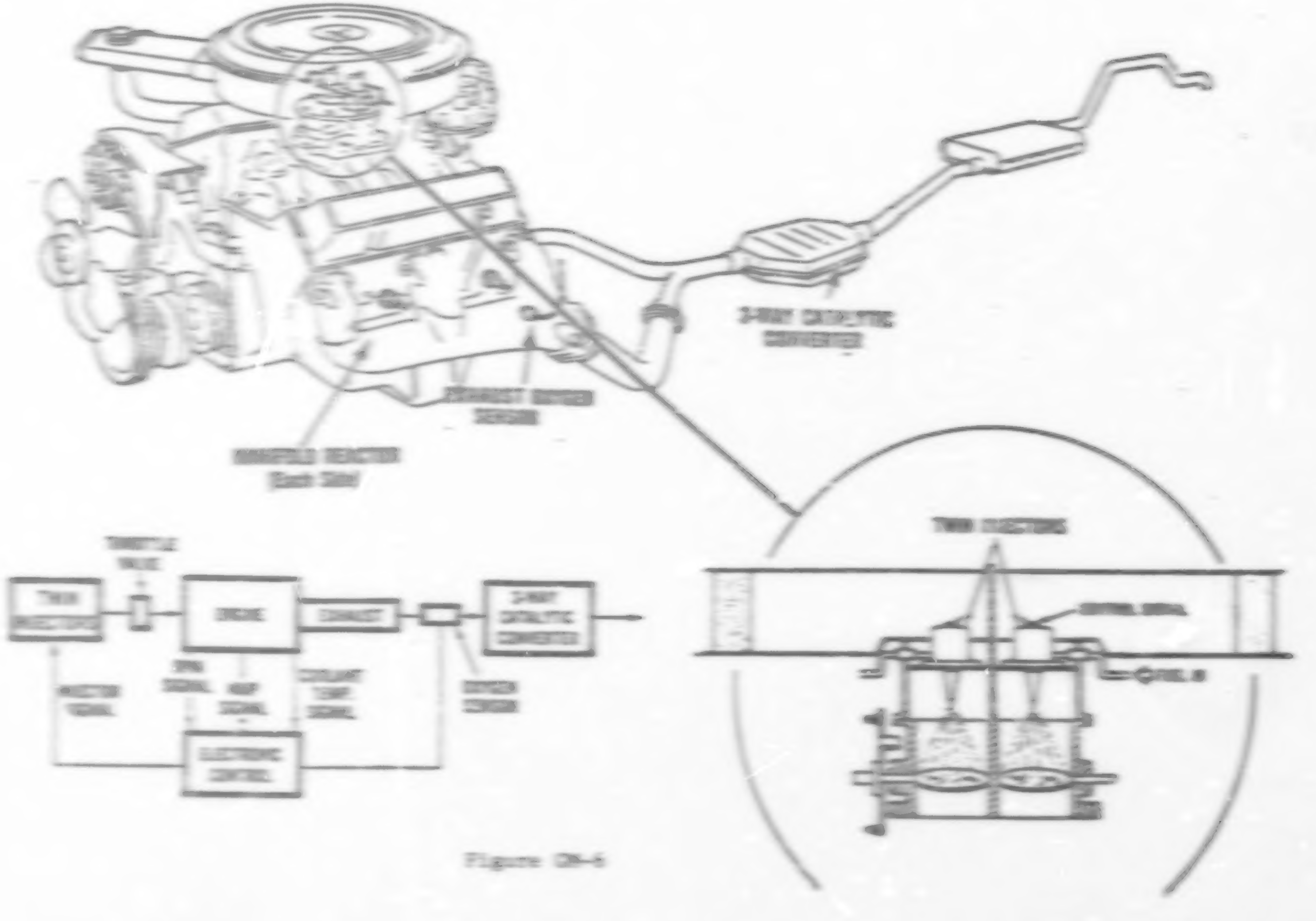

3-WAY CATALYTIC CONVERTER
EXHAUST OXYGEN SENSOR
MANIFOLD REACTOR (Each Side)
THROTTLE VALVE
TWIN INJECTORS
ENGINE
EXHAUST
OXYGEN SENSOR
3-WAY CATALYTIC CONVERTER
INJECTOR SIGNAL
RPM SIGNAL
MAP SIGNAL
COOLANT TEMP. SIGNAL
ELECTRONIC CONTROL
TWIN INJECTORS
CONTROL SIGNAL
FUEL IN

Figure OM-6

All the catalytic systems described above relied on precise air-fuel ratio management. GM uses both closed loop electronic fuel injection and carburation. The carburetor systems have closed loop A/F control of both the idle and part throttle circuits. GM prefers to use a carbureted system because of lower costs and, in GM's opinion, a perceived ability to provide emissions control and fuel economy as well as EFI.

To gain production experience, GM plans to introduce on some 1978 California vehicles a closed loop 3-way system targeted at 0.41 HC, 9 CO, 1.5 NOx. These vehicles will use carburetion rather than EFI. Low mileage results of three practice durability vehicles are shown in Table GM-7.

Table GM-7

Low Mileage Results of 3-Way System Targeted at 0.41 HC, 9 CO, 1.5 NOx

VIN	Model	CID	System	Mileage (10^3)	HC	CO	NOx	MPG$_U$
1669	Buick Skyhawk	231	BPEGR, 3-way, O_2 Sensor, ECU Closed loop 2bbl	0	0.18	2.1	0.32	15.9
				5	0.33	11.6	0.14	17.0
				5	0.20	4.8	0.70	17.0
RS#2	Pontiac	151	Ported Slot EGR, 3-way, O_2 sensor ECU, Closed loop 2bbl	0	0.30	3.17	0.91	18.9
				5	0.27	5.20	0.78	21.4
				5	0.29	5.80	0.96	21.9
RS#3	Pontiac Astre	151	Same as RS #2	0	0.34	4.14	0.52	19.2
				5	0.32	4.80	0.70	21.8

GM closed their discussion of catalytic treatment of NOx by providing their estimates of lead time, production difficulties, and technological advancements at standards of 0.41 HC, 9 CO, 1.0 NOx; 0.41 HC, 9 CO, 0.4 NOx; 0.41 HC, 3.4 CO, 1.0 NOx; or 0.41 HC, 3.4 CO, 0.4 NOx. Since, only some of the GM vehicles described previously are running below the levels of 0.41 HC, 9 CO, 1.0 NOx, GM feels that meeting their target of 1980 for all vehicles for closed loop control is going to be difficult and that the chance for all closed loop control for 1981 California vehicle is greater. This statement is made in light of limited 1978 (151 and 231 CID) introduction of vehicles in California. GM's timetable for faster introduction or total nationwide production by 1980 depends on the construction of an O_2 sensor production facility, closed loop carburetor tooling release, more "practical" catalyst rhodium loadings, solution of the development problems surfaced to date, and the results of the limited 1978 California production. GM indicated that meeting levels below 0.41 HC, 9 CO, 1.0 NOx will require improvements in catalysts and in fuel metering.*

Other Conventional Engine Studies

GM reported extensive results obtained with systems which do not use catalytic control of NOx. The systems are detailed below.

Lean Reactor/Converter Systems

GM has continued to try to develop a lean reactor/oxidation catalyst (LR/OC) system to meet a standard of 0.41 HC, 3.4 CO, 2.0 NOx with a lower limit system potential of 1.5 NOx. A fleet of three 350 CID Chevrolet Monte Carlo vehicles were durability tested to assess the potential of meeting these emissions goals. The results are shown in Table GM-8. One additional vehicle (65357) had an A/F calibration designed to improve fuel economy. Low mileage results of this vehicle were 0.22 HC, 1.8 CO, 1.7 NOx with no loss in fuel economy as compared to a similar 1977 data vehicle.

A LR/OC system is also installed on two 151 CID L-4 Pontiac engines. Low mileage emission results are 0.23 HC, 1.03 CO, 1.3 NOx with 19.1 MPG_U. Durability testing continues with these vehicles.

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* GM Advanced Emission Control System Development Progress, Submitted to EPA, 15 December 1976, page VII-68.

Table GM-8

Lean Reactor/Converter Durability Vehicles*

VIN	Mileage (10^3)	FTP Results HC	CO	NOx	Fuel Economy MPG_U	MPG_H	MPG_C
65381	0	0.21	1.4	1.5	12.0		
	5	0.19	1.6	1.4	12.6	18.8	14.8
	10	0.26	3.2	1.5	12.4		
	15	0.25	2.1	1.6	12.6		
	20	0.30	4.5	1.4	12.1		
	25	0.22	1.2	1.2	12.9		
	30	0.31	2.0	1.3	12.9	19.2	15.1
	35	0.35	2.7	1.4	12.7		
	40	0.33	2.5	1.1	12.6		
	45	0.39	3.5	1.1	12.3		
	50	0.41	2.0	1.2	12.4	18.3	14.5
65382	0	0.20	1.2	1.5	12.2		
	5	0.18	1.0	1.3	12.1	17.1	13.9
	10	0.22	1.7	1.2	12.3		
	15	0.29	1.7	1.6	12.5		
	20	0.35	2.2	1.3	12.7		
	25	0.34	2.7	1.3	12.7		
	30	0.30	2.3	1.3	12.5	18.3	14.6
	35	0.29	2.3	1.4	12.0		
	40	0.25	2.3	1.3	11.7		
	45	0.31	3.5	1.2	11.7		
	50	0.42	5.2	1.3	11.7	17.3	13.7

---

* All vehicles Chevrolet Monte Carlo, 350 CID, A3, 4bbl, HPEGR, EFE, 135 cu in./side lean reactors cold spark adv/retard, 260 cu in. OC.

Table GM-8 (continued)

VIN	Mileage (10^3)	HC	CO	NOx	MPG_U	MPG_H	MPG_C
65328	0	0.14	1.0	1.7	11.0		
	5	0.13	1.3	1.4	11.5	17.5	13.6
	10	0.15	2.1	1.3	11.7		
	15	0.15	2.0	1.5	12.0		
	20	0.17	2.2	1.4	12.1		
	25	0.20	2.3	1.3	12.1	17.9	14.2
	30	0.24	3.0	1.2	12.4		
	35	0.26	3.4	1.3	12.6		
	40	0.26	2.8	1.2	12.7		
	45	0.18	1.2	1.1	12.3		
	50	0.20	1.4	1.2	12.0	17.5	14.0

GM stated that the LR/OC system offers no advantage over an OC/AIR system at standards of 0.41 HC, 9 CO, 1.5 NOx.

At standards of 0.41 HC, 3.4 CO, 1.0 NOx, GM has attempted to develop two vehicles with a reactor calibration richer than stoichiometric, manifold air injection, and an underfloor oxidation catalyst. Zero mile results on a Vega with a 2.3 litre engine with proportional AIR control showed 0.10 HC, 2.0 CO, 0.7 NOx with 18 MPG_U. A 305 CID Chevelle had zero mile average results of 0.29 HC, 1.38 CO, 0.63 NOx with 12.0 MPG_U.

GM attempted to meet 0.41 HC, 3.4 CO, 1.0 NOx without resorting to a reduction catalysts by using high EGR rates, AIR, and OC. GM reported low emission levels with poor driveability and high losses in fuel economy (10-30%) when compared to 1977 Federal certification vehicles, according to GM. Average results are listed below.

Table GM-9

GM 1.0 NOx Target Oxidation Catalyst Systems

		FTP Emissions (gm/mi)			Fuel Economy		
Engine	Vehicle Weight	HC	CO	NOx	MPG_U	VIN	1977 Durability Vehicle MPG_U (Range)
350 V-8	4500	0.18	1.35	0.70	10.4	(7168)	
		0.21	1.68	0.74	11.0		12.3-13.7
250 L-6	4000	0.26	1.35	1.16	13.9	(7148)	13.9-15.0
1.6 litre L-4	2250	0.22	2.39	0.70	22.8	(7110)	
		0.22	2.36	0.67	23.5		21.6-24.3

Another experimental system consists of lean manifold reactors, oxidizing catalysts, lean carburetor (approximately 18:1), back pressure EGR (10-

15%), modified intake manifold for improved air-fuel mixture and EGR distribution, and a cold spark advance/retard mechanism for improved warm-up emission control. In addition, the effect of increasing engine displacement for a given vehicle weight was studied to determine the effects of lowering BMEP. Results of this study indicates that while the emission goals of 0.18 HC, 1.5 CO, 0.6 NOx were met on an experimental basis, driveability and fuel economy were adversly affected.

Other Development Efforts

GM has continued to work on alternative engines, emission control components, and other components to achieve various levels of emission standards or fuel economy improvements.

Diesel Engine

350 Cubic Inch Engine for MY 1978

GM is planning to introduce a Diesel engine for MY 1978 in some light duty vehicles and light duty trucks. The engine is based on the 350 CID Oldsmobile V-8 gasoline engine. The bore, stroke, and deck height are common with the gasoline engine. It uses a divided combustion chamber, a glow plug for starting assist, a rotary distributor injection pump, and pencil nozzles. The vehicle will have a larger starter motor and possibly two batteries. A longitudinal section of the engine is shown on figure GM-7, and details of the combustion chamber are shown on figure GM-8.

GM feels that the Diesel will be 25% better in fuel economy, compared to gasoline power on an equal performance basis. Performance and fuel economy data are shown on Table GM-10.

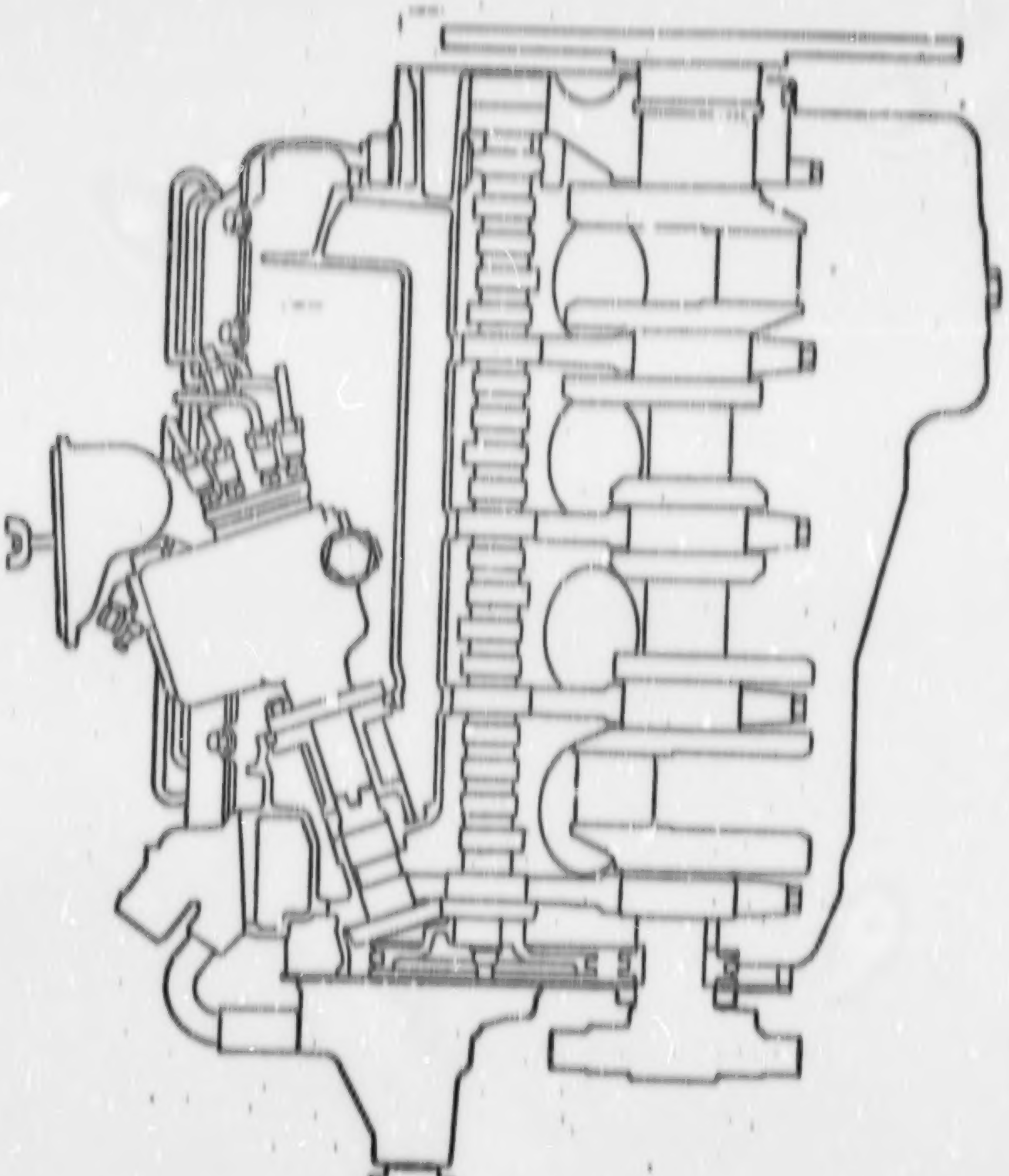


Figure GM-7
350 CID V-8 Diesel

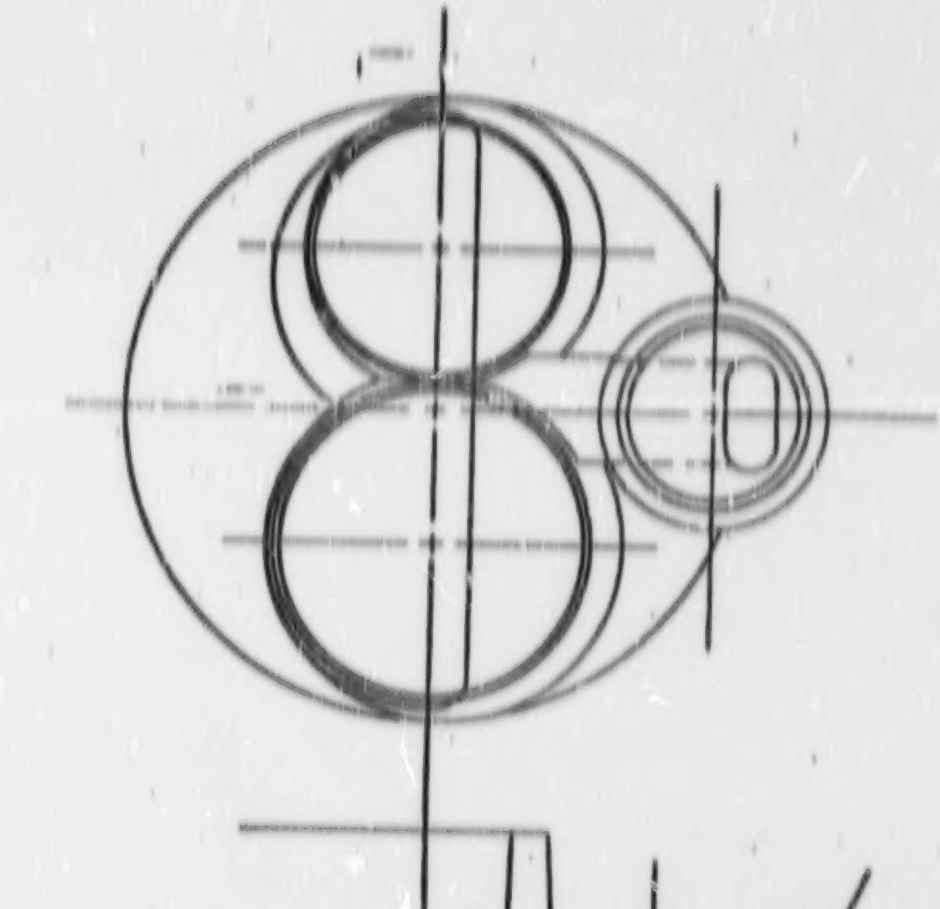


Figure GM-8

GM Diesel Combustion Chamber

Table GM-10

Road Test Performance and Fuel Economy

4500 # Cars

	0-60 MPH	City Traffic	Interstate 55 MPH	50 MPH Constant
260 V-8 Gasoline	18 Sec.	15.9	19.3	21.4
350 V-8 Diesel	18 Sec.	19.2	25.0	27.0
Improvement (MPG)		3.3	5.7	5.6
Improvement (%)		21%	30%	26%

5500 # Trucks

	0-60 MPH	City Traffic	Interstate 55 MPH	50 MPH Constant
292 L-6 Gasoline	18 Sec.	11.9	12.6	13.8
350 V-8 Diesel	19 Sec.	15.8	18.0	19.9
Improvement (MPG)		3.9	5.4	6.1
Improvement (%)		33%	43%	44%

It can be seen from Table GM-10 that GM's fuel economy improvement estimate may be conservative for the light duty truck. Table GM-11 shows the emissions and fuel economy comparisons for the automobile comparison. No data were presented for the light duty trucks shown on Table GM-10.

Table GM-11

Emissions - EPA Fuel Economy

4500# Inertia Weight Cars

	Emissions			EPA Fuel Economy		
	HC	CO	NOx	MPG_u	MPG_h	MPG_c
260 Gasoline	0.50	6.2	1.99	15.4	21.1	17.5
350 Diesel	0.58	1.9	1.63	19.4	27.7	22.4
Improvement (MPG)				4.0	6.6	4.9
Improvement (%)				26%	31%	28%

GM has produced 18 engines on a pilot production line. The engines were targeted for a 1.5 HC, 15 CO, 3.0 NOx emission standard. The average, highest, and lowest emissions with the corresponding fuel economy results from vehicle tests are shown on Table GM-12.

Table GM-12

Emissions and EPA Fuel Economy Range
350 V-8 Diesel

Eighteen New Engines on Experimental Pilot Production Line.

1.5 HC, 15 CO, 3.0 NOx Design Target

	Emissions			EPA Fuel Economy		
	HC	CO	NOx	MPG_u	MPG_h	MPG_c
Average	0.93	2.78	1.72	16.5	24.7	19.4
Highest	1.23	3.29	2.02	17.7	26.6	20.8
Lowest	0.71	2.43	1.45	15.6	22.7	18.2

Other Diesel Studies

GM is apparently conducting an extensive Diesel development program. Some of their work has been on the Opel Diesel, currently produced in Germany, but not imported into the U. S.

Figures GM-9 and GM-10 show the effects of EGR on BSFC, smoke, HC, CO, and NOx for the Opel engine at two different load/speed conditions. At the lighter load condition (Figure GM-9) there is little effect on BSFC and BSHC for EGR rates in excess of 25%. NOx is improved and smoke and CO performance are degraded with EGR. At the heavier load point (Figure GM-10) EGR rates beyond 15% appear to degrade everything except NOx. These two figures indicate the possible need for an EGR system that can control EGR rate based on load and speed.

Figure (H-9)

OPEL DIESEL 126 L-4
1100 R.P.M. 50% LOAD

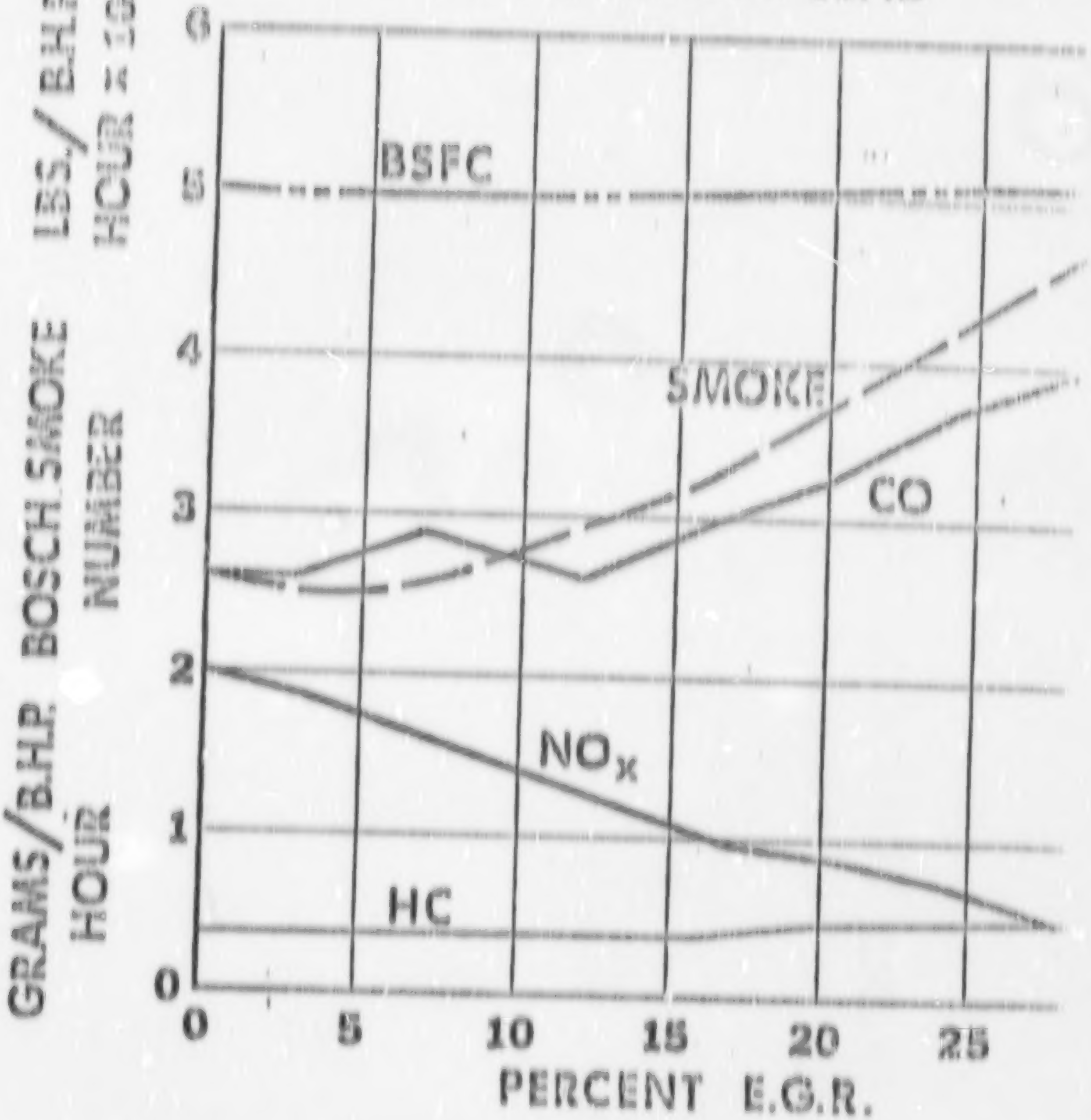


Figure OH-10

OPEL DIESEL 126 L-4
2000 R.P.M. 75% LOAD

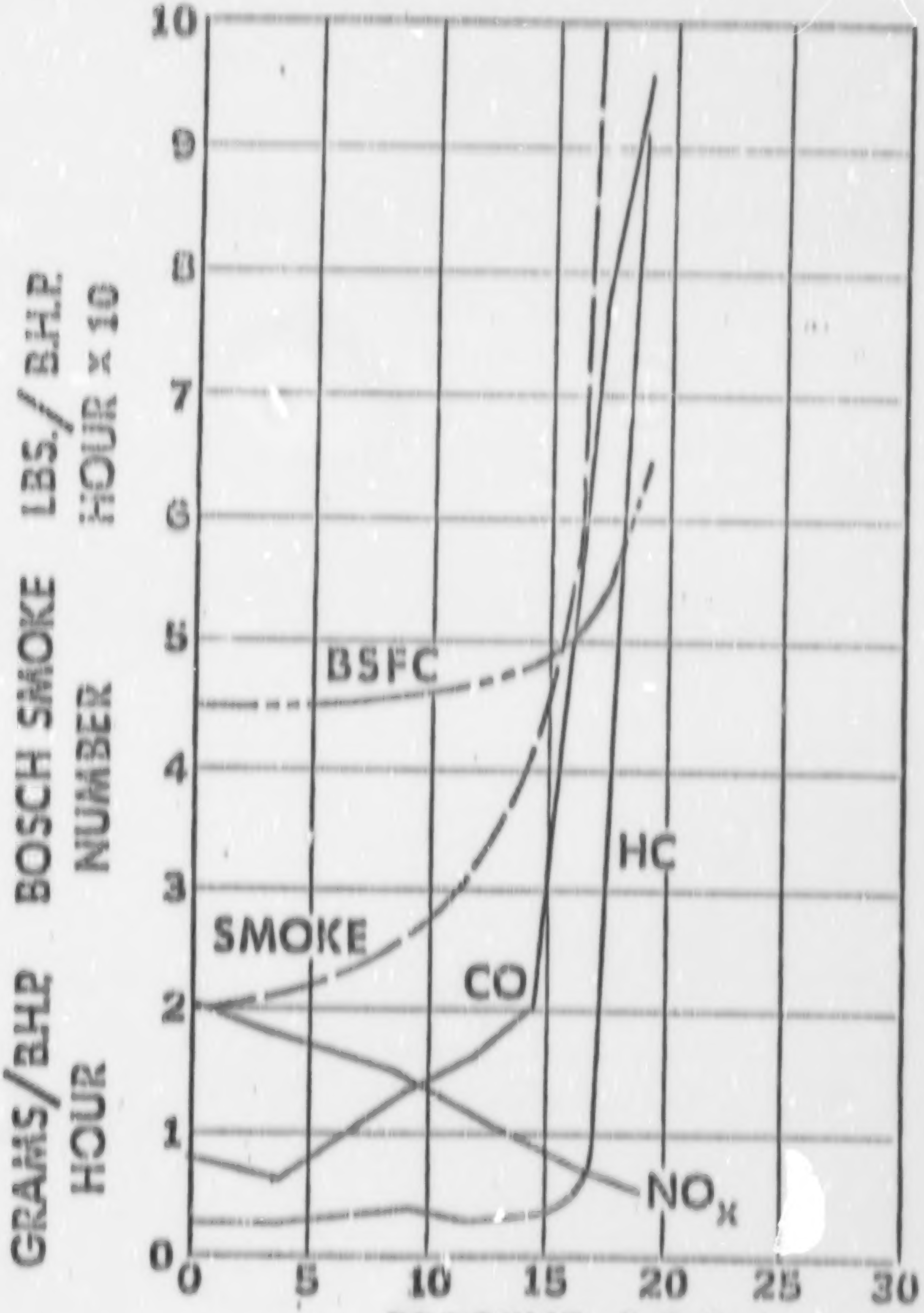


Figure GM-11 shows hot start emission test results from an Opel as a function of road load per cent EGR. HC and CO are seen to increase substantially above 10% road load EGR. Fuel economy was improved by EGR up to about 15% EGR and then declined somewhat at higher EGR rates.

GM reported data in their status report on the effects of EGR and retard on vehicles using EGR and timing retard. The results are shown in Table GM-13.

The HC and CO results shown in Table GM-13 at the lowest NOx level are much lower than the results indicated in Figure GM-11. Table GM-14 shows other GM data on an Opel showing similar results but in greater detail. Note that the use of Electronic EGR allows values of 0.27 HC, 1.30 CO, 0.71 NOx to be achieved, with a negligible (-0.4%) effect on fuel economy. The information does not indicate if the Electronic EGR was used to achieve 0.37 NOx.

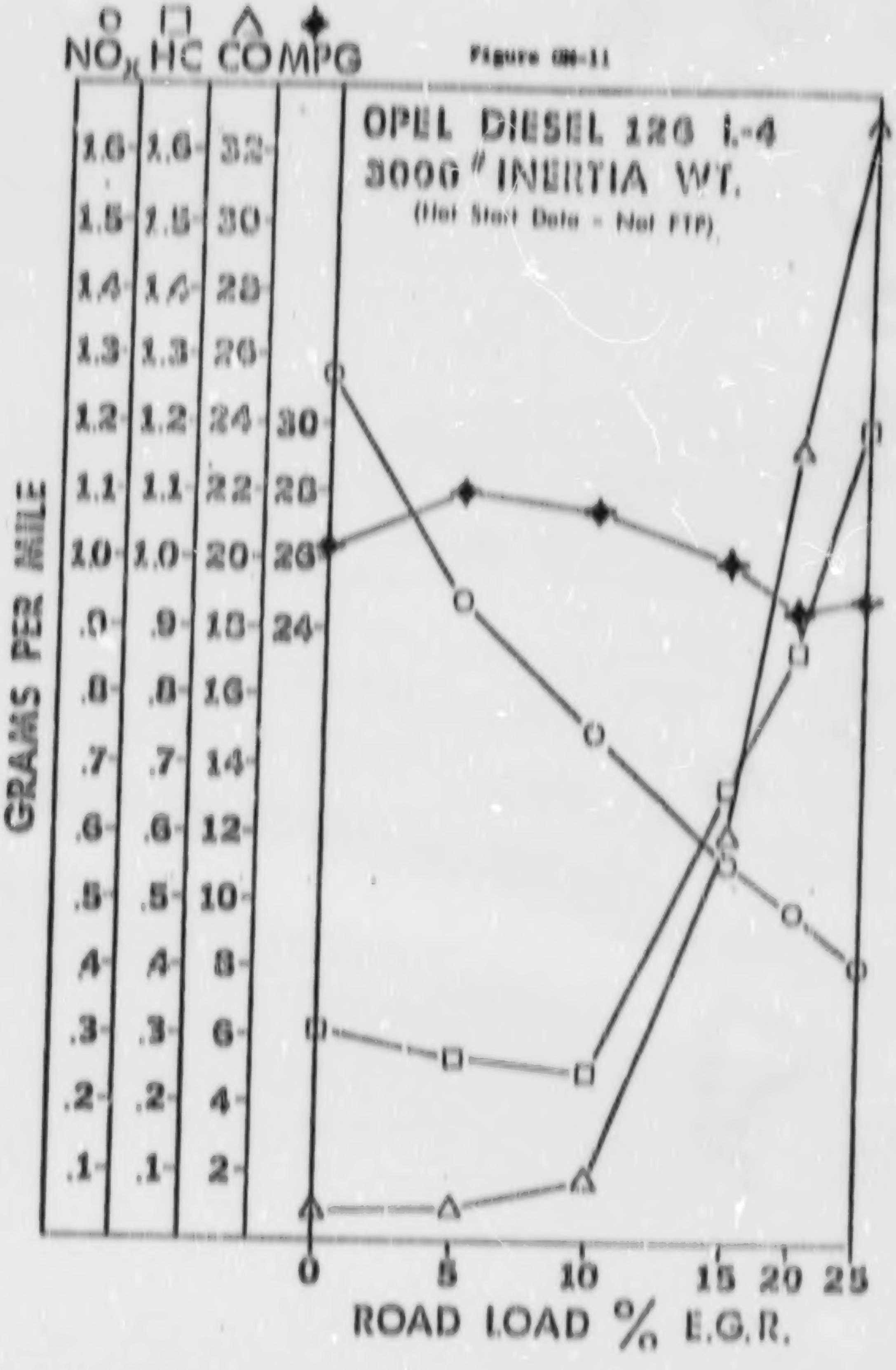
Table GM-13

EGR/Timing Results on Diesel Vehicles

	1975 FTP (gm/mi)			Fuel Economy
	HC	CO	NOx	MPG
Baseline (2500 IW)	0.17	0.75	1.20	29.0
4° Basic retard	0.57	1.10	0.97	25.5
Baseline (2500 IW, AT)	0.27	0.90	1.30	28.3
With EGR	0.30	1.20	0.80	28.0
Baseline (3000 IW, AT)	0.31	0.80	1.30	26.2
EGR for lowest NOx	0.78	10.80	0.37	25.8

An attempt to achieve lowest NOx is shown in the last set of data in the above table for a 3000 lb IW vehicle with an automatic transmission.

Figure 06-11



NOTE: CAR-TO-CAR VARIABILITY AND CAR DURABILITY COULD BE SERIOUS PROBLEMS UTILIZING EGR.

Table GM-14

Diesel Emissions with Exhaust Gas Recirculation

Opel Diesel 126 L-4
3000 lb. Inertia Weight

HC	CO	NOx	MPG_u	
0.31	0.81	1.27	26.2	Baseline (10.8 lb. Air/Mile)
0.27	1.30	0.71	26.1	Electronic EGR
0.38	10.8	0.37	25.8	EGR for Lowest NOx

GM has also conducted evaluations of the effect of timing and EGR on emissions and fuel consumption on the 350 CID engine. Figures GM-12 and GM-13 show the effect on the engine of injection timing at two load/speed points.

GM's results with EGR on the 350 CID engine are shown on Table GM-15. Note that the use of EGR and the redesigned combustion chamber resulted in a 69% reduction in HC, a 26% reduction in CO, a 7% reduction in NOx, and a 7% increase in fuel economy.

Table GM-15

Diesel Emissions with Exhaust Gas Recirculation

Oldsmobile Diesel 350 V-8
4500 lb. Inertia Weight

HC	CO	NOx	MPG_u	
0.58	1.9	1.63	19.4	Baseline (17.7 lb Air/Mile)
0.19	1.3	2.65	20.6	Chamber Configuration redesigned for minimum HC
0.18	1.4	1.51	20.7	With EGR

Figure 08-12

OLDSMOBILE DIESEL 350 V-8
1100 RPM 25 % LOAD

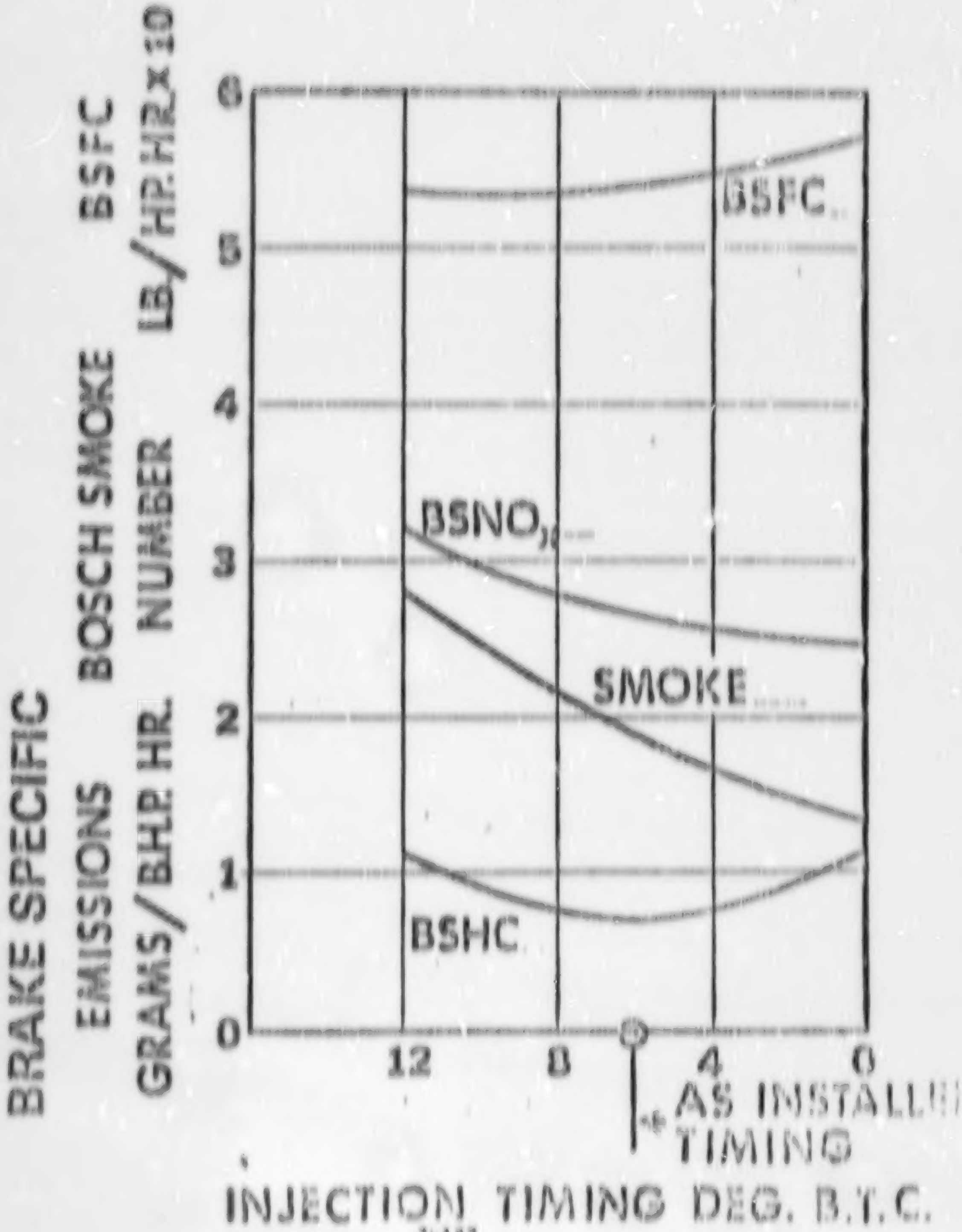
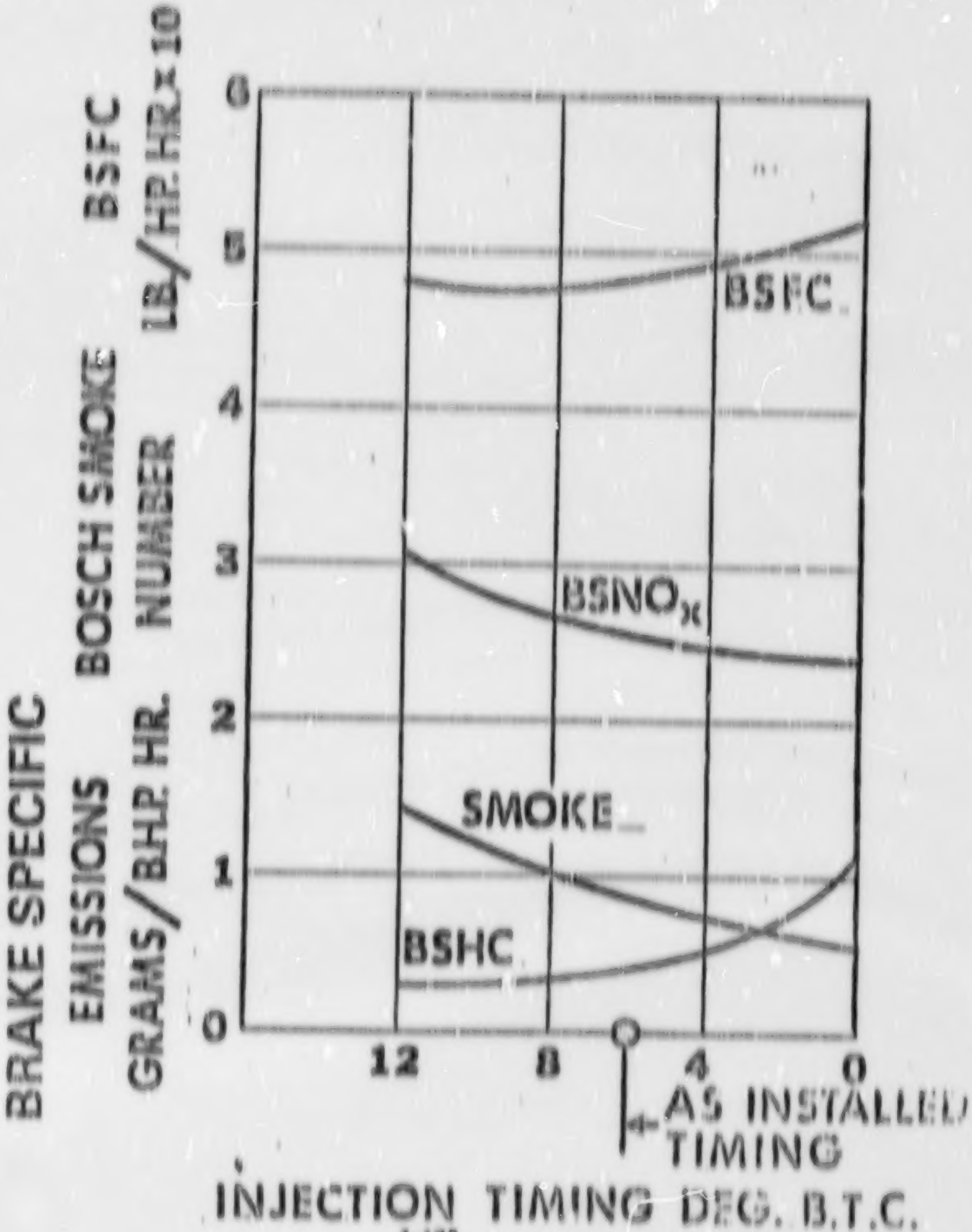


Figure 08-13

OLDSMOBILE DIESEL 350 V-8
2000 R.P.M. 50 % LOAD



GM has an extensive program to study Diesel particulate. An outline of the program is shown in Table GM-16.

Table GM-16

General Motors Diesel Exhaust Particulate Investigation Programs

I. *Particulate Measurements* - Evaluating and in some cases developing measuring equipment for particle volume, size, weight and surface area. Engineering Staff and Research.

II. *Particulate Formation Study* - Understanding the process by which particulates are formed in the combustion process. Research.

III. *Engine Modification* - Investigation of the effect of engine mechanical changes on particulate formation. Oldsmobile and Engineering Staff.

IV. *Fuel Additives* - Effect of "Smoke Reducing" and other fuel additives on particulate formation. Engineering Staff.

V. *Particulate Traps and Incineration* - Design and development of particulate traps and incinerators, including catalytic converters. Engineering Staff.

VI. *Particulate Health Effects* - Health effects of Diesel exhaust particulates. Research Bio-Medical Sciences Department and Wayne State University.

As can be inferred from Table GM-16, the program seems to be a wide-ranging one.

In addition to the aforementioned Diesel particulate studies, GM apparently has conducted or will conduct studies for the measurement of particulate mass from engines on engine dynamometers and on vehicle dynamometers. Particulate samples will be analyzed by a variety of techniques including scanning electron microscopy, thermogravimetric analysis, gas chromatography, and x-ray diffraction to determine composition, topography, structure, volatility, and combustibility.

Several types of smoke meters will be used to establish correlation between the indicated opacity and the mass of particulate emissions.

Two experimental Diesel-powered cars were tested at several driving conditions. The total particulate emissions, given in the following data, ranged from about 200 to 800 milligrams per mile. The sulfate emissions were also determined and were generally between 10 and 15 milligrams per mile. This is equivalent to about 1-1/2% of the fuel sulfur (0.24%) burned.

Particulate Emissions: Experimental Diesel Cars

Driving Cycle	Total Particulate - milligrams/mile	
	Car D-84609	Car D-67135
1975 FTP	830	750
S-7	540	440
HFE	370	390
Idle	-	120*
30 mph	440	240
40 mph	280	250
50 mph	260	290
60 mph	300	240

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* milligrams per minute

GM provided very sketchy details of the modifications to combustion chambers and fuel injection equipment to reduce particulate formations that are being evaluated in engine dynamometer tests. For example, no details were given concerning a special electromagnetic fuel injection system with flexible features including independent pilot injection control which is now operational. Nor were there any details given regarding the several approaches to improve fuel delivery into the combustion chamber and reduce mixing time that will be evaluated and include: (1) high injection pressure, (2) vortex generators, (3) prechamber insulation, (4) pilot injection, (5) outward opening injectors, and (6) moving injection pattern.

Of equal concern to EPA is GM's brief description of their fuel additive work to reduce Diesel particulate emissions. No details were given other than work was underway with these additives. Not only is EPA concerned with Diesel particulate emission, but other unregulated emissions which may be produced with the use of fuel additives.

GM reported work on particulate trapping techniques but revealed no testing results. One method under consideration is the incineration of trapped particulates. The concern for Diesel particulate may require closer monitoring of these types of results.

New Diesel Engines

GM is working on other Diesel engines. The engines are shown on Table GM-17.

Table GM-17

Additional Diesel Engines
Under Consideration by GM

Engine Type	Displacement
V8	260 CID
V6	200 CID
L-4	150 CID

GM's position on the Diesel's capabilities at various emission standards is shown in Table GM-18.

Table GM-18

GM Position on the Diesel at Various Emission Standards

Emission Standard (gm/mi)			Diesel Development Status
HC	CO	NOx	
0.9	3.4	2.0	Currently developed engine can meet this standard.
0.41	3.4	2.0	Achievable with additional development time. May require a new combustion chamber and nozzle with some increase in noise level.
0.41	3.4	1.5	Will probably require exhaust gas recirculation (EGR)* to control NOx with increased particulate emissions.
0.41	3.4	1.0	EGR* is required. NOx level has not been achieved on an engineering basis.
0.41	3.4	0.4	Currently not attainable with Diesel engines.

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* The adverse effect of EGR on engine durability may preclude its use. Further development is required to eliminate particulate damage to engine parts.

GM appears to have a large Diesel program. Not much detail was reported to EPA in GM's status report. In fact, the information contained in six of the previous nine tables was not reported to EPA in GM's status report.

Lean Burn Engine

GM stated that this engine concept had potential to eliminate the use of of EGR and secondary air injection while retaining good emissions levels, driveability, and fuel economy with less emission control hardware than present systems. However, GM feels the system has a NOx limit of 2.0

gm/mi and offers no potential unless technological advances in air-fuel metering occur that reduce air-fuel ratio variation. No mention was made of the current status of this program.

Stratified Charge Engine (SCE)

GM has an extensive ongoing stratified charged engine program. Some of the subjects under consideration are shown in Table GM-19.

Table GM-19

GM Stratified Charge Engine Activities

Fundamental Studies

1. Combustion Process Modeling - Emissions
2. Combustion Bomb Studies
3. Combustion Photography
4. Schlieren Photography - A/F Distribution
5. Holographic Visualization - A/F Distribution

Dynamometer Evaluation

1. 3 Valve Prechamber Engine
2. 2 Valve Split Port Engine
3. Fuel Injected Prechamber Engine
4. Fuel Injected Direct Injection Engine
5. Staged Combustion Engine
6. Diesel Engine

In-Car Evaluation

1. 3 Valve Prechamber Engine
2. Fuel Injected Prechamber Engine
3. Diesel
4. TCCS
5. Porsche SKS
6. Honda CVCC

Test results with the 3 Valve Prechamber Engine are shown in Table GM-20.

Table GM-20

3 Valve Prechamber Engine Program

Engines: L4 140 CID, V8 350 CID
Vehicles: 3000 IW Vegas, 4000 IW Novas, 4500 IW Chevelles,
5000 IW Impalas
Emission Systems: Reactors, Converters, EGR

4500 IW Comparison

	HC	CO	NOx	MPG$_U$
3 Valve - Reactor	0.4	3.4	1.4	10.0
3 Valve - Converter	0.3	0.6	1.5	12.2
Conventional lean - Converter	0.3	0.9	1.6	12.8

3000 IW Comparison

	HC	CO	NOx	MPG$_U$
Phase I	0.3	3.0	1.2	17.5
Phase II	0.3	3.5	1.4	17.5
Phase III	0.6	6.0	1.9	17.0
Conventional Lean	0.3	5.0	1.6	17.5

In their Status Report, GM reported the data shown in Table GM-21.

Table GM-21

Emission - Fuel Economy Relationship for Carbureted Stratified Charge Engine Car

FTP Emissions - gpm			FTP Fuel Economy - MPG$_U$
HC	CO	NOx	
0.3	0.9	1.6	12.8
0.3	0.6	1.5	12.2
0.2	0.5	0.7	11.6

Two of the results in Table GM-21 look like two of the results under the 4500 IW comparison on Table GM-20. However, the vehicle at 0.3 HC, 0.9 CO, 1.6 NOx, 12.8 MPG$_U$ on both tables is labeled a conventional engine on Table GM-20 and is shown as a carbureted stratified charge engine on Table GM-21.

As was the case for the Diesel, some information (Table GM-19, Table GM-20) was not reported to EPA in GM's status report.

Staged-Combustion Engine

The staged-combustion engine embodies two engine concepts in one engine: charge stratification and hydrogen supplementation. GM did considerable two-cylinder work on this concept. A 4500 lb IW vehicle with this concept had emission results of 0.45 HC, 2.8 CO, 0.37 NOx. GM indicated that the system complexity, poorer fuel economy, and durability problems preclude engine development and the work on this concept has been suspended.

Variable-Stroke Engine

GM is monitoring the progress being made by Sandia Livermore Laboratories on their multi-cylinder, variable-stroke engine.

Gas Turbine Engine

Work continues at GM on gas turbine components directed toward the development of a practical passenger-car system. Work on a prechamber combustor continued last year. Preliminary testing indicates the potential for meeting 0.41 HC, 3.4 CO, 0.4 NOx emission standards with this combustor plus programmable electronic control. No vehicle emission results were reported. Work using alternative fuels, various rear axle ratios, and tires was conducted to assess potential fuel economy improvements for the present generation GM gas turbine.

Stirling and Rotary Engines

GM continues to monitor ERDA funded Stirling engine programs, plus continues to postpone introduction of the rotary while conducting fundamental research on the rotary.

Other Emission Control Components and Concepts

Electronic Controls

GM is working on electronic control of carburation in conjunction with their 3-way catalyst system development. Very limited details or discussion were provided by GM on their accomplishments and problems with this concept. They did, however, state that they were experimenting with electronic control of EGR, air injection, and idle speed. Electronic control inputs would be engine speed, manifold vacuum, coolant temperature, barometric pressure, humidity, ambient temperature, engine knock, and engine surge.

A number of vehicles were assembled to evaluate electronic controls. All the following vehicles had electronic ignition timing and EGR control, while some use choke, AIR, and idle speed control. These vehicles were targeted to an emission level of 0.41 HC, 3.4 CO, 1.0 NOx.

Table GM-22

Electronic Control Vehicle Data*

Vehicle	Emissions (gm/mi) HC	CO	NOx	Fuel Economy (mi/gal) City	Hwy	Comp.	Electronic Controls
Pontiac 151/3000#	0.23	2.5	0.76	20.7	26.2	23.2	Choke & idle speed
Buick 231/3500#	0.26	2.1	0.71	17.9	23.5	20.1	AIR (modulated)
Oldsmobile 350/4000#	0.24	1.3	0.67	14.8	20.4	16.9	Idle speed
Oldsmobile 403/4500#	0.29	1.9	0.68	13.0	18.3	14.9	Choke & idle speed
Cadillac 425/4500#	0.25	1.9	0.76	11.1	16.6	13.0	Choke & idle speed

* All had electronic control of spark timing and EGR in addition to those specified.

One vehicle employing exhaust manifold reactors as well as a production catalyst, electronically controlled spark timing, EGR, cold enrichment, and idle speed produced the following results: 0.25 HC, 1.2 CO, 0.75 NOx with 13.2 MPG_u, 18.6 MPG_h, and 15.2 MPG_c.

GM mentioned briefly that they were developing an engine knock limiter to take advantage of increased engine compression ratio by optimizing spark advance through electronic control over the entire operating range of the engine. The system uses a transducer to sense engine knock and uses this signal to control spark timing in order to maintain an acceptable level of knock with a given octane fuel.

Engine "surge" is being considered as an input for electronic control. No details were given.

GM feels electronic control has potential for achieving 0.41 HC, 3.4 CO, 1.0 NOx without the need for reducing catalysts.

Staged EGR

The staged EGR system being developed utilizes a variable EGR orifice sized to provide two discrete EGR rates, one for first and second gear operation, and the second rate for third gear operation. The results shown below are for a vehicle targeted for 2.0 NOx.

System	FTP Emission, gm/mi			Fuel Economy		
	HC	CO	NOx	MPG_u	MPG_h	MPG_c
BPEGR	0.50	3.6	1.5	14.1	19.1	16.0
Staged EGR	0.46	3.7	1.5	14.3	20.0	16.4

Cold Spark Advance/Retard Units

When used with leaner choke scheduling, the concept of advancing spark timing during cold engine operation has improved driveability and reduced emissions. A drawback is that this reduces the warm-up rate of catalysts and/or reactors. GM has added some vacuum retard spark to the Cold Spark Advance (CSA). This reduces total spark advance during light load engine operation and increases the warm-up rate.

The special spark timing schedule is only used for the first few minutes of engine operation. When the engine is warmed-up, conventional vacuum spark advance is used. During the warm-up period, the CSA/retard unit schedules spark timing opposite to current production technique, i.e., as engine vacuum levels drop, spark timing is advanced. Thus, during high load operation, the increased spark advance improves driveability, while at light load the decreased spark advance increases the exhaust temperatures which increase warm-up rates. The CSA/retard spark system requires additional hardware on the vacuum advance unit and a coolant temperature sensor. Three Chevrolets with 1977 Federal emission controls and equipped with 350 CID V-8 engines and 260 cu in. underfloor catalysts have been tested with CSA and with CSA/retard. The results are shown as follows:

Table GM-23

CSA and CSA/Retard Results

Chevrolet: 350 CID V-8, CVS, EGR, no AIR, 260 cu in. Underfloor Catalyst

System	FTP Emissions--gm/mi HC	CO	NOx	Fuel Economy MPG_u	MPG_h	MPG_c
CSA	0.27	1.5	1.2	11.2	--	--
CSA/Retard	0.22	1.3	1.1	11.6	16.7	13.4

Chevrolet: 350 CID V-8, Lean Burn, no EGR, no AIR, 120 cu in. reactors, 260 cu in. Underfloor catalyst

System	FTP Emissions--gm/mi HC	CO	NOx	Fuel Economy MPG_u	MPG_h	MPG_c
CSA	0.21	0.94	1.1	11.3	16.5	13.2
CSA/Retard	0.16	0.82	1.0	11.7	16.5	13.5

Chevrolet: 350 CID V-8, AIR, EGR, 260 cu in. Underfloor Catalyst

System	FTP Emissions--gm/mi HC	CO	NOx	Fuel Economy MPG_u	MPG_h	MPG_c
CSA	0.25	3.61	1.42	12.5	--	--
CSA/Retard	0.19	3.02	1.34	12.4	--	--

As shown, the CSA/retard system reduced HC emission with no major effect on fuel economy.

Improved Catalyst Warm-up Program

The objective of this program is to study methods of conserving engine exhaust heat in order to provide more rapid converter warmup. Use of an air-gap (double walled) exhaust pipe was successful in reducing catalyst light off by a factor of 2.92 and reduced HC by 30%, CO by 40% and increased NOx by 3.5%.

Another study evaluated the effect of catalyst location and type on exhaust emissions. The results are summarized as follows:

For every 25 inches the production pelleted oxidation catalyst is moved downstream from the manifold take down (a) the time required to reach 600°F increases by 20 seconds (b) HC emissions increase by 0.03 gm/mi and CO emissions increase by 0.3 gm/mi. Comparing a monolithic catalyst to a pelleted catalyst at the same location, the time to reach 600°F is reduced by 40 seconds.

7.1.4.2 Systems to be Used at Various Emission Levels

Table GM-1 lists the fuel economy percentage losses and MPG ranges for each of the proposed standards which GM perceives will be associated with meeting these levels.

1.5 HC, 15 CO, 2.0 NOx

At this level, GM will continue to use its present configuration of oxidation catalysts, BPEGR and engine modifications. GM indicated there was a 5% fuel economy loss in 1977, compared to what could have been achieved at the 1976 standards (1.5 HC, 15 CO, 3.1 NOx), EPA calculations indicate there was a 10.4% gain in fuel economy for GM with all changes considered and a 3.2% fuel economy gain due to system optimization at lower emission levels.*

0.9 HC, 9 CO, 2.0 NOx

Additional AIR would be added to the system used at the previous emission levels. GM maintains that lead time is insufficient due to shortage of production capacity to produce enough air pumps for use in 1978. Lead time for construction of new production facilities precludes using this system in 1978 across the board, according to GM. GM predicts no fuel economy penalty at this level.

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* "Light Duty Automotive Fuel Economy-Trends through 1977; J. D. Murrell, et al., SAE Paper 760795, October 18-22, 1976, page 8.

0.41 HC, 9 CO, 1.5 NOx (1977 California Levels)

Systems to meet these levels would be similar to 1977 California systems consisting of an oxidation catalyst, BPEGR, air injection, and improved carburetion. Limited introduction of a closed-loop 3-way catalyst system is planned for two engine families in California. Fuel economy penalty for the former systems can be as much as 11% on a composite sales weighted average, according to GM. Low mileage 3-way catalyst system results (Table GM-7) show a modest fuel economy improvement over comparable 1977 durability vehicles. GM stipulates that it would be impossible to use the 1977 California system nationally in 1978 due to lead time needed to contract new air pump and EGR valve facilities. GM cited differences in the certification procedure between California and EPA as a factor which may preclude use of the 1977 California system on a national basis.

0.41 HC, 3.4 CO, 2.0 NOx

At these levels, [illegible]els that an oxidation catalyst, BPEGR, AIR, (or PULSAIR), improved carburation, and the use of lean reactors will be the first choice system. However, improved catalyst performance and precise air-fuel ratio control are necessary to meet these standards.

0.41 HC, 3.4 CO, 1.0 NOx

GM's system choices at these levels and at the following levels, are either: 1) oxidation catalyst, AIR, EGR (limited to vehicles with high power-to-weight ratios), 2) 3-way catalysts, EGR, and closed loop air-fuel ratio control. Those vehicles which attempt to reach 1.0 NOx without reducing catalysts have exhibited large fuel economy penalties and poor driveability, according to GM. GM continues to maintain that technology does not exist which demonstrates that reducing catalyst systems can be viable at these levels without fuel economy penalties.

0.41 HC, 3.4 CO, 0.4 NOx

Systems that employ the use of a reduction catalyst would be used at this level according to GM. Again GM maintains the unknowns associated with deterioration, durability, etc. limit both the demonstration and development of these systems at this level except on an individual vehicle basis.

7.1.4.3 Durability Testing Programs

Since GM assumed that the 1978 model year vehicles would be carryover from 1977 vehicles, with the exception of more stringent evaporative emission controls, they apparently have not conducted any sizeable pre-certification durability fleet testing of prototype 1978 vehicles. Table GM-24 summarizes those vehicles which GM reported to be on extended mileage accumulation.

The first three vehicles (63294, 63295, and 65343) in Table GM-24 reflects GM's durability evaluation of a monolithic catalyst rather than their current production underfloor pelleted catalyst. Preliminary data indicates these systems appear capable at levels of 0.41 HC, 3.4 CO, 2.0 NOx. No fuel economy data were presented for the extended mileage tests. GM plans to run a 43 car fleet to assess monolithic catalyst durability in the field.

Of the 3-way catalyst equipped vehicles, vehicles 64384 and 65375 were reported in last year's status report. The mileage accumulation is now complete to 50,000 miles. At levels of 0.41 HC, 3.4 CO, 0.4 NOx, vehicle 65375 failed to meet the NOx standards at 35,000 miles while failing CO at 45,000 miles. This vehicle failed all three pollutant levels at 50,000 miles. Vehicle 64384, equipped with an Engelhard 3-way monolithic catalyst, failed to meet all these levels at lower mileage.

No explanation was given for the difference in fuel economy between the two vehicles. Vehicle 65344 is a durability test with a larger engine using a pelleted 3-way catalyst. Both NOx and CO remain a problem with this vehicle.

Vehicle 64534 represents all of the mileage accumulation data to date on the Oldsmobile Diesel engine.

Vehicle 46145 and 46262 are mileage accumulation data on the turbocharged V-6 Buick engine planned for 1978 introduction at 1977 emission levels.

GM reported that it was their intention to get 301 CID engine performance with the fuel economy of a naturally aspirated 231 CID engine by turbocharging their 231 CID engine. Vehicle 46145 did not use the ESC (knock limiter) system incorporated on the certification durability vehicles. GM selected the AiResearch turbocharger because of lower cost and better production availability.

No mention was made of any large scale emission control system fleet testing as GM has done in the past with their Corporate Durability Test Fleet. GM orally reported that they have less than 300 vehicles under all types of testing.

Table GM-24

Durability Vehicles

VIN	Model	CID	Control System	Mileage (10^3)	HC	CO	NOx	MPG_u	MPG_h
63294	Nova	305	Monolith	5,000	0.25	1.2	1.55		
			OC	10,000	0.28	2.1	1.50		
				15,000	0.36	2.3	1.50		
				20,000	0.30	1.8	1.60		
				22,300	0.34	1.9	1.65		
				22,500	0.37	2.0	1.60		
				25,000	0.33	1.6	1.55		
				30,000	0.36	2.4	1.70		
				35,000	0.28	2.0	1.25		
				40,000	0.28	2.2	1.10		
63295	Nova	305	Monolith	5,000	0.28	0.8	1.07		
			OC 210 cu in.	10,000	0.32	1.0	1.07		
				15,000	0.35	0.8	1.20		
				20,000	0.40	1.1	1.20		
				22,300	0.40	1.2	1.30		
				22,500	0.44	0.9	1.30		
				25,000	0.42	1.2	1.10		
				30,000	0.41	1.0	1.20		
				35,000	0.42	1.0	1.20		
				40,000	0.42	1.2	1.25		
				45,000	0.44	1.3	1.40		

Table GM-24 (con't)

VIN	Model	CID	System	Mileage (10^3)	HC	CO	NOx	MPG_u	MPG_h
63343	Nova	250	Monolith	0	0.28	2.0	1.40		
			OC (205 cu in.)	5,000	0.36	1.6	1.40		
				10,000	0.34	1.6	1.50		
				15,000	0.30	2.7	1.55		
				20,000	0.32	2.3	1.65		
				22,500	0.34	3.2	1.45		
				22,500	0.52	3.3	1.55		
				25,000	0.32	1.2	1.45		
63344	Nova H/B	350	3-way (pelleted),	0	0.30	3.41	0.33	12.6	
			closed loop 4bbl,	5	0.22	5.67	0.34	12.6	
			O_2 sensor, BPEGR	10	0.25	5.3	0.52	13.0	
				15	0.25	5.37	0.62	13.0	
				20	0.26	5.50	0.63	13.0	
				22.5	0.25	5.20	0.68	12.8	
				22.5	0.29	3.40	0.57	13.3	
				30	0.31	3.75	0.45	13.3	
63375	Vega	2.3 litre	EFI, O_2 sensor, 9.0 CR BPEGR,	0	0.18	2.42	0.21	16.9	23.5
				0	0.19	2.36	0.26	17.6	
				5	0.26	3.81	0.39	17.7	
				10	0.23	4.38	0.64	-	
				10	0.17	2.35	0.37	17.1	
				15	0.20	3.49	0.38	18.1	
				15	0.18	3.18	0.27	17.9	
				20	0.22	2.82	0.32	17.7	
				22.5	0.29	4.60	0.32	18.1	
				22.5	0.22	3.92	0.55	18.2	
				22.5	0.18	2.81	0.39	17.4	
				25	0.18	2.94	0.35	17.4	
				30	0.20	3.88	0.36	19.0	
				30	0.21	3.10	0.40	19.3	
				35	0.23	3.10	0.68	18.7	

Table GM-24 (con't)

VIN	Model	CID	System	Mileage (10^3)	HC	CO	NOx	MPG_u	MPG_h
				35	0.18	2.53	0.41	17.8	
				40	0.27	3.75	0.51	17.5	
				45	0.38	5.13	0.60	18.8	
				45	0.33	4.60	0.57	17.5	
				50	0.57	6.03	0.57	17.2	
			New cat	50	0.20	1.60	0.37	17.6	
64384	Vega	2.3 litre	Same as 64375 exc. w/Engelhard monolithic 3-way catalyst	0	0.26	1.69	0.16	17.3	23.5
				0	0.24	2.54	0.29	20.2	
				5	0.22	1.84	0.43	21.0	
				10	0.21	2.14	0.71	21.7	
				10	0.21	2.19	0.76	21.6	
				10	0.29	4.60	0.41	21.1	
				10	0.24	2.71	0.27	19.5	
				15	0.30	3.52	0.73	21.3	
				15	0.32	3.67	0.33	20.9	
				20	0.30	4.14	0.29	20.5	
				22.5	0.68	9.16	0.40	20.0	
				22.5	0.29	3.75	0.33	20.4	
				30	0.34	3.03	0.51	21.5	
				35	0.48	6.60	0.51	20.6	
				35	0.31	4.56	0.62	20.8	
				37.5	0.32	4.61	0.56	22.8	
				40	0.36	4.33	0.44	23.8	
				43	0.38	6.33	0.32	20.9	
				50	0.33	5.23	0.65	19.5	
64534	*	350	Diesel Engine	0.5	0.80	2.1	1.70	18.4	26.8
				5	0.60	2.0	1.60	19.8	28.8
				10	0.80	2.0	1.65	20.0	29.6
				15	1.05	2.0	1.60	19.8	29.5
				20	0.85	1.8	1.50	20.8	29.7
				25	1.00	2.0	1.58	20.4	28.6

Table GM-24 (con't)

VIN	Model	CID	System	Mileage (10^3)	HC	CO	NOx	MPG_u	MPG_h
46145	Buick	231	Rajay	0	0.53	6.0	1.60	17.9	
			Turbocharger	5	0.83	9.3	1.40	18.1	
			EFE, OC, EGR	10	1.08	23.0	1.43	16.0	
				15	1.70	26.1	1.49	18.2	
				22	1.43	16.0	1.22	18.1	
				25	1.05	11.5	1.70	16.4	
				30	0.85	11.2	1.65	16.9	
				35	0.69	10.2	1.56	16.9	
46262	Buick	231	Same as 46145	0	0.52	6.4	1.30	16.1	
			exec. AiResearch	0	0.62	4.8	1.48	17.4	
			turbocharger	5	0.43	2.5	1.78	17.8	
				6.3	0.60	4.4	1.72	18.3	
				10	0.62	3.9	1.72	17.8	
				10.7	0.78	4.8	1.80	18.0	
				11.4	0.73	3.8	1.69	18.8	
				11.5	0.72	5.1	1.55	18.8	

7.1.4.4 Progress and Problems Areas

Progress and Problems - 1978 Model Year

Because GM apparently believes that the 1978 emission standards will remain at the 1977 levels, little progress towards meeting levels in 1978 lower than the current standards was noted. GM steadfastly maintains that any levels lower than 1.5 HC, 15.0 CO, 2.0 NOx are impossible to meet nationwide in 1979. However, GM will be introducing 3-way catalyst technology on a limited basis in California, but at NOx levels no lower than 1.0 gm/mi, according to GM. There are also indications that GM will be continuing their vehicle weight reduction program that started in model year 1977.

According to GM, catalyst durability and the fuel metering quality necessary for 3-way catalyst operation remain as the major development problems for attaining statutory levels. Based on this year's status report submission, GM apparently has had only limited success with vehicular 3-way catalyst durability. GM also appears to have possible problems with their closed-loop carburetion which is so necessary for good 3-way catalyst operation.

Progress and Problems at Levels at Other than Statutory

At levels of 1.5 HC, 15 CO, 2.0 NOx, GM will have no difficulty and will continue to raise their corporate fuel economy figure. GM maintains there will be difficulties encountered with the new evaporative emission test and interaction of the evaporative emission control system with exhaust emissions, but GM appears to have the capabilities of resolving these difficulties. Work on the Oldsmobile Diesel has progressed at these emission levels. While it is encouraging to see the introduction of this fuel efficient engine, there appears to be a lack of the aggressive development reported that may be needed to attain lower emission levels.

GM will have to add AIR and recalibrate only some of their 1977 vehicles to attain levels of 0.9 HC, 9 CO, 2.0 NOx as many of their 1977 vehicles are well below these levels. GM maintains that the lead time needed to build new production facilities for air pumps and BPEGR would preclude expanded use of these systems in 1978. Here again, GM will have to expend little effort to meet these levels other than the corporate commitment to produce sufficient air pumps and EGR valves to meet projected sales levels.

In order to extend nationwide the present California levels, 0.41 HC, 9 CO, 1.5 NOx, GM would have to recalibrate many of their 49 state vehicles. Using the calibrations found on the 1977 California vehicles may not be directly applicable since those vehicles were allowed to line cross, had a methane correction, and may have used the Federal deterioration factor rather than their own (California system) deterioration factor. A positive factor at these levels will be the introduction of two engine families in California using closed loop 3-way catalyst technology.

At both 0.41 HC, 3.4 CO, 2.0 NOx and 0.41 HC, 3.4 CO, 1.0 NOx, GM has made some progress with systems which have reduction catalysts and systems using lean calibrations, lean reactors and oxidation catalysts. However, lack of durability fleets using these concepts pose a problem in projecting a time for the introduction of this technology.

GM provided scant cost data with this year's submission.

7.2. Independent Developers

7.2.1. The Bendix Corporation

Bendix responded to EPA's request for a status report submission by discussing Bendix's emission control development efforts since their last testimony at the EPA Suspension Hearings in 1975. Bendix stated that until approximately one year ago, Bendix's activities centered around development of electronic fuel injection (EFI) on a system basis in conjunction with industry efforts to meet emissions standards. Recent revaluation of Bendix's engineering and marketing strategies has resulted in a change from a system-only approach to that of a component supplier as well. Consequently, Bendix has for the past year been accelerating their efforts in the development of engine sensors, actuators, and digital electronic control units (DECUs). See Figure Bendix-1.

The components supplied by Bendix consist of four major subsystems: (1) fuel delivery, (2) air induction, (3) sensors, and (4) ECU. Bendix described these subsystems thusly: The fuel delivery subsystem, as installed in a vehicle, includes the fuel tank pickup and boost pump, the electrically-driven, constant displacement, main fuel pump, a filter, the fuel manifold, injectors for each cylinder, a fuel pressure regulator, and supply and return lines.

The air induction subsystem includes the intake manifold and throttle body assembly for primary air flow control, as well as an integral fast idle air valve controlled by engine temperature and an electric heating coil. The fast idle valve supplies increased cold starting air around the closed primary throttles.

The sensor subsystem includes several primary engine sensors. An intake manifold pressure sensor measures absolute pressure in the intake manifold

DIGITAL CONTROL UNIT

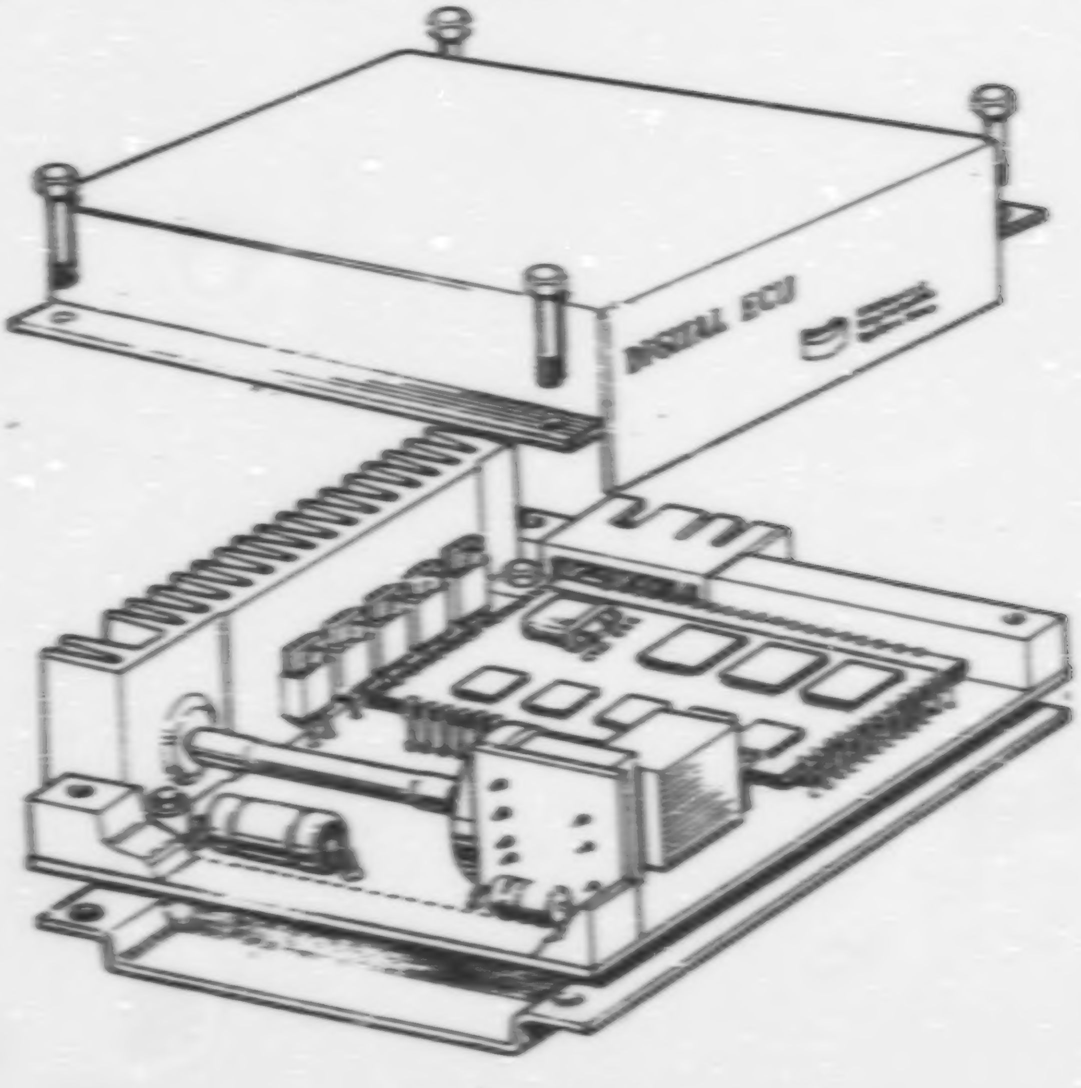
DIGITAL ECU

Figure Bendix-2

to provide a parameter for continously computing air flow to the engine. An air temperature sensor is located in the intake manifold to provide a correction for the computation of the engine air flow. A speed sensor, mounted integrally to the ignition distributor, provides engine speed data for volumetric efficiency corrections, computation of air flow, and engine-phasing data for synchronizing injector timing. A temperature sensor, installed in the engine coolant jacket, provides a signal for computation of fuel enrichment requirements for cold start and engine warm-up. A throttle position sensor provides information for acceleration fuel enrichment (AE) and wide open throttle enrichment.

The electronic control unit receives information from the sensors and, using a selected control logic, computes the exact fuel requirement relative to air flow for each cylinder on each engine cycle. This is translated into injector-open time signals which energize the solenoid-type injector valve to deliver a specified quantity of fuel to each cylinder. The ECU calibration is flexible enough to provide precise fuel requirements over a wide range of engine performance requirements.*

Bendix has field experience with EFI equipped vehicles at both ends of the vehicle weight spectrum. During MY '75/'76, Bendix provided EFI for approximately 3200 Cosworth Vegas. They also supplied EFI units for '75/'76/'77 MY Cadillacs. Bendix reported that while overall performance and driveability were reported to satisfy most vehicle owners, there were two problems which were driveability oriented; the tip-in response off closed throttle sometimes contains a slight "hesitation" causing the car to stumble slightly, and a hot restart condition which results in noticeable engine speed oscillation between the hot restart and subsequent driveaway.

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* Development Status of Electronic Emission Controls at the Bendix Corporation Electronic & Engine Control Systems Group, page 1-1, 1-2.

In order to improve driveability with EFI, Bendix has conducted specific test and development programs. The problem of tip-in anomalies will be solved by use of an injection technique referred to as simultaneous double fire (SDF). The hot start instability problems will be solved by enriching the fuel injection calibration on a time decay basis as a function of coolant temperature at the time of hot restart.

The present production system uses two-group injection, where each cylinder receives the computed fuel requirement in a single injection pulse for each engine cycle of two engine revolutions. With simultaneous double fire (SDF), the per-cycle fuel requirement for each cylinder is delivered with two injection pulses (one for each engine revolution). For steady state conditions, then, each pulse provides one half of the cycle fuel requirement; however, during transients it is possible to update the computation between the first and second injection and more closely match fuel to air flow. Apparently, the SDF system, like the two-group system, does not control each injector individually.

SDF injection timing (and engine speed information) is obtained directly from the ignition primary instead of from the two distributor-driven reed switches presently used in production for group injection. This requires added ECU circuitry for counting down but an overall cost benefit is realized.

Results of the various programs generally show significant improvements in throttle tip-in response and in other transient modes with some idle roughness penalty. A 5500 lb IW vehicle with a 500 CID engine was converted from the 2-group to SDF injection mode with the results shown in Table Bendix-1.

Table Bendix-1

SDF Versus 2-Group Injection

	HC	CO	NOx	MPG_U
2-Group	0.967	15.79	1.517	10.46
SDF	0.59	9.30	2.20	10.75

Bendix reported that this vehicle demonstrated improved idle quality and complete elimination of the off-closed-throttle tip-in hesitation and hot restart rollout. The SDF emissions calibration had not been fully optimized at the time the above emissions data were recorded. It is fully expected that calibration development and possible intake manifold modifications would achieve emissions and fuel economy at least equivalent to that for 3-group injection.

All development programs at Bendix including forward model production and potential customer programs are being done using the SDF injection mode.

Bendix is also developing a closed-loop idle speed control subsystem which is regulated by the ECU. This control maintains a relatively constant warm engine idle speed and also provides idle speed control for cold start and warmup.

Bendix has conducted several programs to investigate fuel economy improvements using EFI systems. One of the programs is to determine the minimum acceptable driveability for fuel cut-off on deceleration and for low idle speed. Bendix reported fuel economy improvements between 3 and 7 percent but with aggravated tip-in hesitation and hot start instabilities. Work continues on this program.

Bendix is also working with a potential customer in a program to apply digital electronic spark advance for improvements in fuel economy. The system replaces the distributor timing pickup, centrifugal advance, vacuum motor, calibrated throttle port, and temperature overrides. Ignition timing is controlled by digital electronics using the inputs from a crank position sensor, a manifold absolute pressure sensor, and a coolant temperature sensor. In addition, the EGR subsystem is controlled in an on/off manner as a function of coolant temperature, and ignition timing corrections are made concurrently with this. Two systems of a prototype configuration have been delivered to the customer for his calibration development. The program is now nearing the demonstration phase with a goal of model year 1979 production. Future addition of full digital electronic EGR control is intended.

Bendix has also conducted development programs to assess exhaust emission improvements obtainable using an EFI system. Their development work has again been in conjunction with the ultimate user of the system.

Zero mile testing of a 3-way catalyst, closed loop EFI, oxygen sensor, and back pressure EGR system on a 350 CID, 4500 pound inertia weight vehicle showed results of 0.45 HC, 6.58 CO, 1.21 NOx with fuel economies of 12.1 MPG_u and 17.0 MPG_h. These fuel economies compare to the Cadillac Seville with 1976 fuel economy of 15 MPG_u and 21 MPG_h. Further work continues to improve the closed loop techniques.

A vehicle equipped with a 350 CID engine, and a 3-way catalyst, tested at 4500 IW, targeted at 0.41 HC, 3.4 CO, 1.0 NOx has demonstrated 0.45 HC, 2.9 CO, 1.0 NOx with 16.4 MPG_u at low mileage. Driveability was rated very good.

Work with a vehicle equipped with a 140 CID engine, closed loop air flow sensing EFI, a 3-way catalyst, tested at 3000 IW, targeted at statutory emission levels has achieved zero mile emissions of 0.2 HC, 2.3 CO, 0.2 NOx.

Bendix also has supplied EFI systems to EPA for a heavy-duty engine program at SwRI and to A. P. Parts (Questor) for development work with the Questor-Reverter emission control system.

The advanced development work reported by Bendix included work on a digital ECU (DECU) and engine sensors. The principal reported advantages of the digital controller over its analog counterpart include increased accuracy in digital computation over the range of operating temperatures, improved reliability, and lower cost. In addition, the DECU has the ability to use more complex schedules for control of additional engine variables such as spark timing and EGR.

Bendix has undertaken a major development effort in the area of engine sensors. Table Bendix-2 displays the type of sensor and sensor concepts under active investigation.

Table Bendix-2

Sensor Type	Concepts Under Investigation
Pressure	Strain Gage Crystal LVDT Variable Capacitance Potentiometric
Air Flow	Vortex Shedding Turbine Swirl Deflecting Vane
Temperature	Wire Wound Thermistor Metal Film Solid State
Position	Potentiometric Reluctance Hall Effect Reed
Exhaust	Zirconium Dioxide (ZrO_2) Titania (TiO_2)

Samples of both the zirconium dioxide and titanium dioxide sensors have been supplied to prospective customers for evaluation. See Figure Bendix-2.

One of the more interesting advanced projects Bendix reported was their efforts to develop single point electronic fuel metering concepts for reduced costs and introduction for model year 1980. While initial work has shown this system has problems inherent with carburetor systems, i.e., fuel preparation and distribution, examples of improved cylinder to cylinder air-fuel distribution and driveability have been achieved. Further optimization work needs to be conducted while attempting to meet presently legislated standards. A schematic of this concept will be found in Figure Bendix-3.

EXHAUST GAS SENSOR

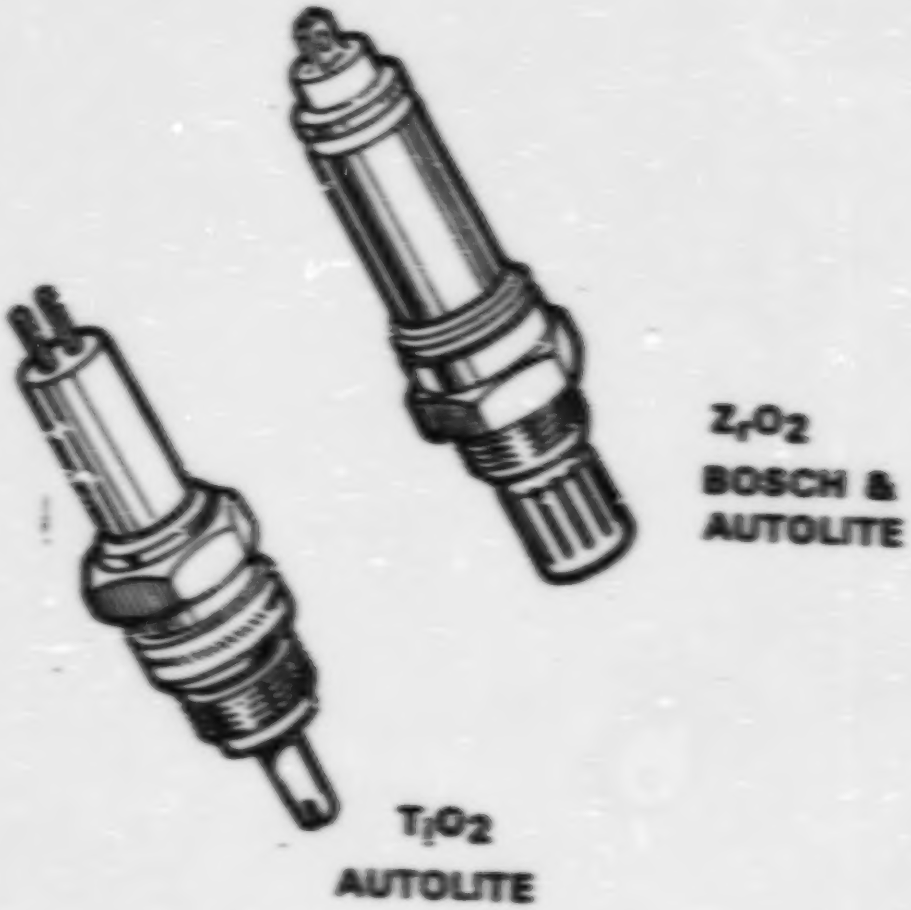
Z_rO_2
BOSCH &
AUTOLITE
T_iO_2
AUTOLITE

Figure Bendix-2

LOW COST FUEL CONTROL SYSTEM

PDM METERING

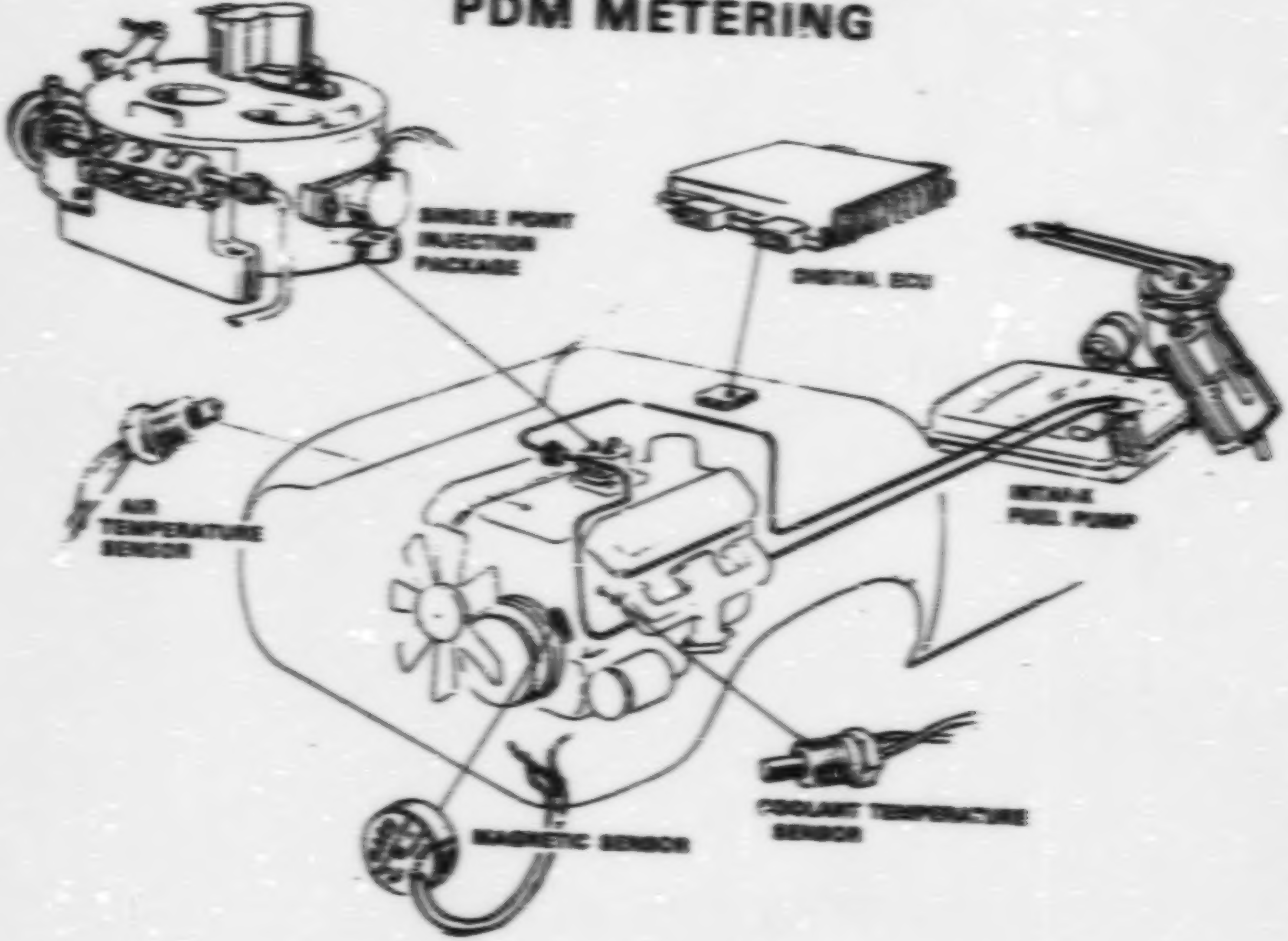
SINGLE POINT INJECTION PACKAGE
DIGITAL ECU
INTANK FUEL PUMP
AIR TEMPERATURE SENSOR
COOLANT TEMPERATURE SENSOR
MAGNETIC SENSOR

Figure Bendix-3

7.2.2. Robert Bosch

Since one of the first demonstrated applications of closed loop three-way catalyst operation incorporated Bosch fuel injection equipment and oxygen sensor, Bosch was asked for a submission for this year's status report. The potential importance of the three-way catalyst technology necessitates an understanding of injection system and oxygen sensor availability, technical difficulties, and system potential. The probability of three-way catalyst introduction may hinge on the availability of fuel injection equipment if feedback carburetion cannot be developed in time to meet production deadlines or if feedback carburetion is not capable of the required emission control.

The Bosch response to the status report submission request was disappointing in that it failed to provide sufficient information to assess the potential of fuel injection equipment availability, cost and demonstrated performance. Bosch provided no cost, lead time, emission and vehicle performance or fuel economy data. They suggested that this information should come from the vehicle manufacturers rather than a component supplier.

Bosch did reinterate that they felt that either their L or K-Jetronic fuel injection system would be an improvement over presently available carburetion systems. For the various emission levels, Bosch stated the following:

A. At levels of 1.5 HC, 15 CO, 2.0 NOx, Bosch feels that port type fuel injection in combination with EGR on engines up to 2 litre displacement is sufficient. On engines over 2 litres, thermal reactors, air pumps, and oxidation catalysts are necessary.

B. For levels of 0.41 HC,3.4 CO,2.0 NOx, the use of oxidation catalysts becomes mandatory, according to Bosch. Additionally lean calibration, pulse air or air pumps are required on larger displacement engines.

C. Bosch maintains that at levels of 0.41 HC,3.4 CO,1.0 NOx the three-way catalyst with feedback fuel injection is superior to either higher amounts of EGR or dual catalyst systems. This type of system is what will be used on the 1977 California Volvo vehicles. Bosch states that low mileage emission results of .2 HC,1.5 CO, .6 NOx have been achieved on a 4 cylinder, 2 litre engine. One difficulty Bosch has encountered with their three-way catalyst work is finding a suitable location for the O_2 sensor on opposed-cylinder and V-type engines. One possible solution is to use two separate closed loops with individual sensors for each engine bank. Bosch would prefer not to use this solution due to cost. Bosch predicts no fuel economy penalty at this level for four cylinder engines, but a potential fuel economy penalty may exist for larger displacement engines. Driveability is rated satisfactory, particularly without EGR.

D. At levels of 0.41 HC,3.4 CO,0.4 NOx, Bosch reports difficulties meeting the NOx standard over 50,000 miles. Bosch maintains the good fuel economy which comes with stoichiometric control will disappear at this level of NOx control. EPA believes that stoichiometric control may still be used at these levels, but EGR may be required for many vehicles.

A benefit of a closed loop fuel injection system is the automatic compensation for temperature and barometric changes, engine wear, and system calibration shifts. Consequently, the vehicle owner has no obvious temptation to tamper with the fuel metering system, unlike the present carbureted systems. Bosch feels their closed loop control is ideally suited to maintain good driveability and to protect against maladjustments at the expense of emissions.

While Bosch may have a parochial interest in furthering the closed loop electronic control system, it is evident to EPA that while these systems provide flexibility in controlling exhaust emissions there is much more work necessary in optimizing all the controlling parameters in a pratical application. Consequently, the following discussion is aimed at providing a basic understanding of closed loop control systems as was provided by Bosch.*

Figure Bosch-1 shows the components constituting closed loop system. The time response of the closed loop system consist of:

- the time response of the controller (normally referred to as ECU)
- the response of the fuel metering system
- the delay for the transport of the mixture from the metering system to the intake valves of the engine
- the transport of the mixture through the engine
- the delay for the transport of the exhaust from the exhaust valve to the lambda (λ) sensor (commonly called O_2 sensor)
- The time response of the lambda sensor.

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* Application of Closed Loop Control to Fuel Metering, H. Eisele and W. Wessel, Robert Bosch GmbH, Stuttgart, W. Germany, no date.

It can be seen that the overall time response is a combination of six individual and partially controllable time constants. How important are each of these constants and what impact do these have on the overall system time response?

The fuel metering system in most cases can be approximated by a first order time delay with the frequency response.

$$F_M = \frac{1}{1 + sT_m}$$

However T_m is normally small and can be neglected.

The transport delay representing the movement of the mixture from the metering system to the intake valve depends on the applied metering system. Bosch indicates that with a carburetor or a single point injection system this time constant can be substantial. For an individual port injection system with the injector mounted close to the intake valves the transport time delay is very small and can be ignored according to Bosch.

The transport of the mixture through the engine is a function of the engine speed.

$$F_E = e^{-sT_E}$$

The movement of the exhaust from the exhaust valve to the lambda sensor is also represented by a transport delay.

$$F_{Ex} = e^{-sT_{Ex}}$$

The time constant T_{Ex} depends on engine speed, engine load and the location of the lambda sensor in the exhaust system.

The time response of the lambda sensor can be approximated by a first order time delay with a very high gain. Figure Bosch-2 shows the output signal of the sensor as a function of the normalised air-fuel ratio lambda.

$$F_S = \frac{V}{1 + sT_S}$$

Time constant T_S depends on the temperature of the sensor. T_S decreases with increasing sensor temperature. For practical purposes the input-output characteristics of the sensor is of the ON-OFF type.

A further refinements of Figure Bosch-1 with appropriate annotated transport delays can be seen in Figure Bosch-3.

Further simplification of Figure Bosch-3 can be achieved by various substitutions for the time parameters T_M and T_{Ex} plus a summation of T_E and T_{Ex} to equal T_T to total transport time through the engine combined with the exhaust valve to lambda sensor transport time. The transport delay T_E for a four stroke engine can be approximated by 3 engine strokes consisting of the compression stroke, expansion stroke and approximately 50% of the intake stroke and exhaust stroke. Therefore, T_E is equal to 3/2 x 1/n, where n represents engine revolutions per unit time. The delay T_{Ex} represents the time it takes the exhaust gas to reach the lambda sensor after the outlet valve opens. This time delay depends on engine speed, engine load and the volume of the exhaust system between outlet valve and location of the lambda sensor. Measurements taken from a typical four cylinder engine application allow the following crude approximation:

$$T_{Ex} = \frac{3}{4}\,\frac{1}{K_L \quad n}$$

With K_L representing the normalised internal engine load; full load corresponds to $K_L = 1$.

As a further simplification of Figure Bosch-3, the first order time delays of block F_M and block F_S can be compensated by lead time constants in the controller. This simplification results in a control loop consisting of a transport delay and a block F_S with a very high proportional gain within a very limited operating range ending up in saturation outside this narrow range. Therefore it is not possible to treat this control loop using known linear techniques. Basically the control loop consists of a transport delay and a block with ON-OFF characteristic.

The frequency response of the controller selected must include an integral portion to assure full compensation of any disturbances to the fixed plant. Although in actual applications a more complicated frequency response is used, a controller with pure integral response allows a very accurate description of the basic behavior of the closed loop as applied to vehicles. Figure Bosch-4 depicts the three essential blocks of the closed loop with the frequency response of the controller, where

$$F_R = \frac{1}{sT_y}$$

Due to the non-linear ON-OFF type characteristic of the lambda sensor the closed loop maintains an oscillation even under steady state conditions. The frequency of the oscillation is determined by the phase shift of the controller with integral response and the transport delay. With the constant phase shift of 90° for the controller the total phase shift results in

$$\varphi = \frac{\pi}{2} + 2\pi f T_T$$

According to feed back control theory a stable oscillation must be expected at

$$\theta = \pi + \nu 2\pi \text{ with } \nu = 0, 1, 2, 3, \ldots$$

This means that the closed loop can oscillate at different frequencies. From the above equations, the frequencies can be derived

$$f_0 = \frac{1}{4T_T}; \; f_1 = \frac{3}{4T_T}; \; f_2 = \frac{5}{4T_T}; \quad \nu = 0, 1, 2$$

This result can also be derived without any calculations from Figure Bosch-5 which shows the output of the different blocks of Figure Bosch-4 for the frequencies f_0 and f_1. The lambda sensor changes the output signal whenever the signal from the transport delay changes from rich to lean mixture and vice versa. The integral controller moves correspondingly to the lean side when the sensor shows rich mixture and towards rich mixture whenever the sensor indicates lean.

For an ideal engine with perfect mixure distribution from cylinder to cylinder, and no outside distrubances the closed loop would oscillate with the frequency f_0. Practical applications, however, show that disturbances quite frequently cause the closed loop to change from frequency f_0 to frequency f_1 and lock in at the higher frequency f_1. Bosch reports higher frequencies than f_1 have not been observed on four cylinder engines in practical applications. This can be explained with the reciprocating mode of the typical gasoline engine transporting mixture on a per stroke basis.

The frequency of the oscillation as shown in the above equation is independent of the integration time constant T_y of the controller. The adjustment of the controller, however, determines the amplitude of the oscillation under steady state conditions and the required time to compensate for a disturbance. As can be derived from Figure Bosch-5 the amplitude A_y of the oscillation is determined by

$$A_y = \frac{T_T}{T_y}$$

A_y defines the deviation from the desired reference at $\lambda=0$ to $\lambda=1$ or vice versa.

For example, the equations derived, frequencies of the closed loop oscillation for a four cylinder engine can be determined at $K_L=1$ representing full internal engine load and $K_L=1/3$ corresponding to 33% of full load.

Example:

At n = 900 1/min.

$K_L = 1$

$T_T = 150$ msec $f_0 = 1.66$ Hz $f_1 = 8.3$ Hz

$K_L = \frac{1}{3}$

$T_T = 250$ msec $F_0 = 1$ Hz $f_1 = 5$ Hz

at n = 3000 1/min.

$K_L = 1$

$T_T = 45$ msec $f_0 = 5.55$ Hz $f_1 = 27.75$ Hz

$K_L = \frac{1}{3}$

$T_T = 75$ msec f_0 3.33 Hz $f_1 = 16.66$ Hz.

The calculated frequencies in this example are close to the measured values from an actual application.

The amplitude of the oscillation under steady state conditions varies with engine speed and engine load. For a controller with a constant intergration time constant T_y the maximum amplitude occurs at idling of the engine. Therefore the actual value of the air-fuel ratio can deviate substantially from the set point at lambda =1, although the controller maintains the desired stoichiometric air-fuel ratio with high accuracy on an average basis. For proper operation of the 3-way catalyst concept it is necessary to achieve an adequate mixing of the exhaust gas from different cylinders in the exhaust manifold and the catalyst over at least a cycle of the closed loop oscillation. The required averaging effect is simplified if the amplitude of the oscillation is kept small, which is also a necessary condition for stable idling of the engine. This means that the time constant T_y of the controller should be large. There are however the contradicting requirements for a controller with fast response to compensate quickly for disturbances, and with slow response to keep the amplitude of the oscillations small, in particular, at low engine speed. The obvious answer is the application of a self-adaptive controller with a variable time constant T_y. During operation the time constant is adjusted depending on engine conditions.

A combination of the above information shows that variation of the amplitude A_y dependent on engine speed and engine load can be derived.

$$A_y = \frac{1}{2\ n\ T_y} \left(1 + \frac{1}{2\ K_L}\right)$$

The above equation also defines the necessary automatic adjustment of T_y if for instance A_y should be kept constant over the full operating range.

Actual emission tests, however, show that a less sophisticated adjustment is sufficient. A one step change of the integration time constant dependent only on engine speed results in a good compromise for stable idling and low emissions.

From the discussion of the closed loop operation it is obvious, however that the proper functioning of the system must be checked at the low frequency f_0. This assures automatically adequate performance at the higher frequency f_1.

The lambda sensor is only operational at temperatures exceeding approximately 300°C. Therefore it is necessary to operate at lower sensor temperatures open loop and to keep the integral contoller output clamped at a selected preset level. This low temperature condition always occurs for a short time after starting a cold engine, and it can also be observed on certain engines during extended periods of idling if the sensor is mounted too far downstream of the outlet valves. For initialisation of the closed loop lambda sensor is warm enough to generate the required proper feedback signal. One possibility in this case is to check the source impedance of the sensor which decreases with increasing temperatures as shown in Figure Bosch-2. This check is complicated because it is unknown whether the engine is operating lean or rich with respect to a stoichiometric air-fuel ratio. One possible approach for the checking procedure is shown in Figure Bosch-6.

After a cold start a checking current is fed through the sensor. The measured voltage decreases with warm-up of the sensor because of the decreasing source impedance. Curve A represents the situation for rich mixture and curve B for lean mixture. In the figure the initialisation for lean mixture is shown. As soon as the measured voltage goes below a preset bias voltage, the controller is started. At the same time the reference voltage of the integral controller, which was held at the bias level, starts to decrease until the value representing warm engine is reached.

After the controller is initialized, the operation of the closed loop is monitored on a continuous basis. This is relatively simple because of the existing oscillating mode of the operation under steady state conditions. It is sufficient to monitor the time between two changes of the sensor output voltage indicating rich or lean mixture. If this time exceeds a preset value, then the controller is clamped and the open loop mode is selected. In this case the initialization check is restarted in order to go back to closed loop operation whenever the necessary conditions are again met.

It is sometimes desirable to operate the system at a point other than at stoichiometry. The lambda sensor Figure Bosch-2 shows a very steep characteristic at stoichiometric air-fuel ratio. This ON-OFF type behavior allows the desired accurate control at lambda = 1 for the 3-way catalyst concept. For certain emission control concepts it is interesting, however, to operate accurately at an air-fuel ratio different from stoichiometry. Electronic means in the controller afford the desired reference adjustment within about plus or minus 5% of lambda = 1.

One obvious way to obtain a reference adjustment with an integral controller is shown in Figure Bosch-7a which depicts the output of the integral controller. The integration time constant is asymmetrical. The slope going up is different from the slope going down. The achieved reference adjustment on an average basis is given by the following equation:

$$\Delta \lambda = \frac{1}{2} T_T \left(\frac{1}{T_{y1}} - \frac{1}{T_{y2}}\right)$$

Unfortunately this reference adjustment is dependent on the transport delay which changes with the operating condition of the engine. Another possibility which avoids this drawback is shown in Figure Bosch-7b. In this case the reference adjustment is independent of the transport delay T_v as given by the next equation

$$\Delta \lambda = \frac{1}{T_v} \cdot \frac{t_z^2}{2}$$

The integrator is forced to continue for a defined time interval t_z after the sensor output changes.

The reference adjustment decreases the frequency of the closed loop oscillation and causes an increase of the amplitude. The influence of frequency and amplitude on idling stability and emission was discussed before and must be carefully considered if reference adjustment is applied.

Consequently, Bosch summarises that closed loop control compensates automatically for:

- tolerances, wear and drift of the engine and the fuel metering system
- changes in the composition of the fuel
- variation of the atmospheric pressure due particularly to different elevations.

Considering these effects, an output range of the controller from lambda = .8 to 1.25 with respect to rated conditions is necessary. The limited range of the controller output allows emergency operation of the engine if a catastrophic failure of the control loop - which cannot be corrected by clamping of the controller should occur.

The previous discussion by Bosch indicates that the engine emission control designers are now faced with not only the normal engine parameters of air-fuel ratio, speed, load, etc. but a myriad of electronic controls which must be tailored for engine operation over the entire speed/load range. While this may seem a formidable task for the design engineer, it indicates the extreme flexibility that electronic controls allow potential for custom tailoring of engines for both good fuel economy and low emission levels.

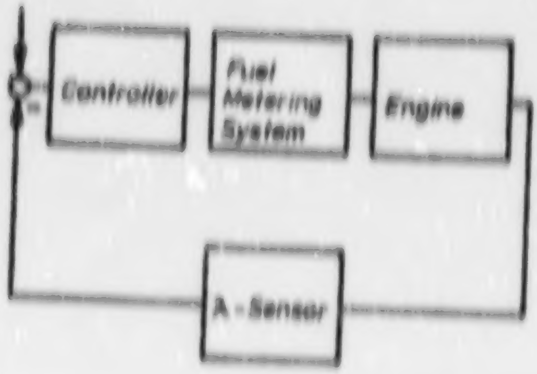

Controller
Fuel Metering System
Engine
λ-Sensor

Figure Bosch-1
Closed Loop Engine Control System

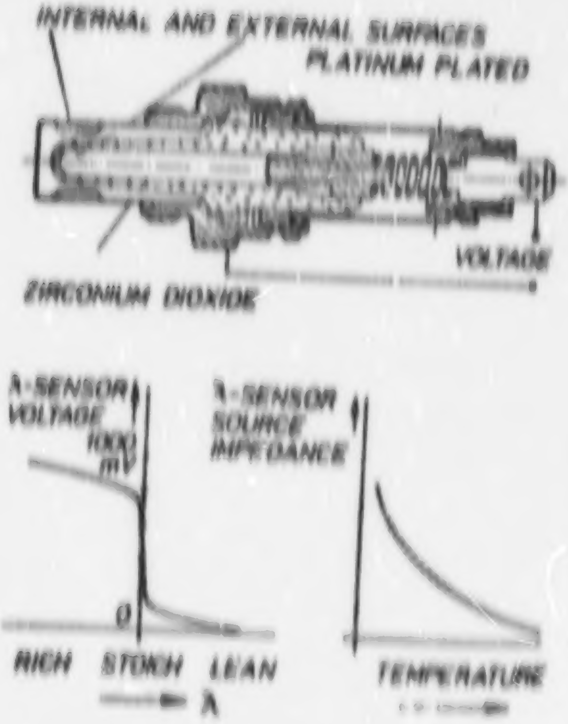

INTERNAL AND EXTERNAL SURFACES PLATINUM PLATED
VOLTAGE
ZIRCONIUM DIOXIDE
λ-SENSOR VOLTAGE
1000 mV
0
RICH
STOICH
LEAN
λ
λ-SENSOR SOURCE IMPEDANCE
TEMPERATURE

Figure Bosch-2
Lambda Sensor

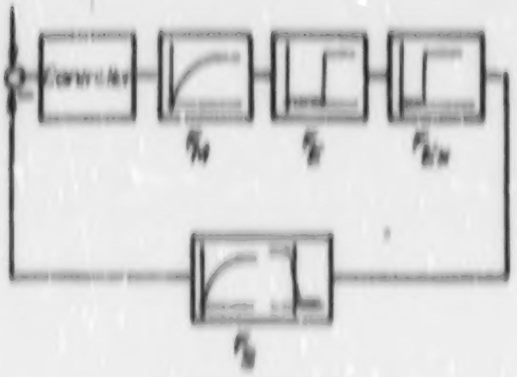

Controller

Figure Bosch-3

Block Diagram of the Closed Loop System

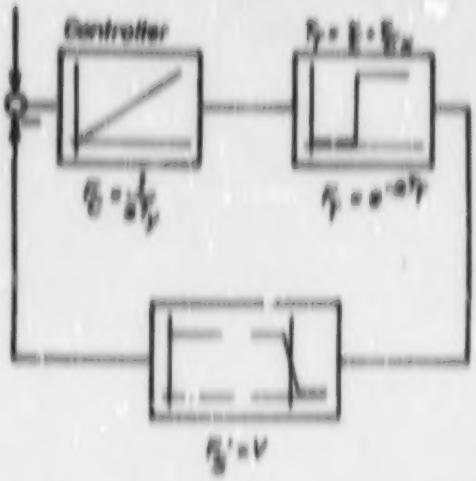

Controller

Figure Bosch-4

Simplified Block Diagram

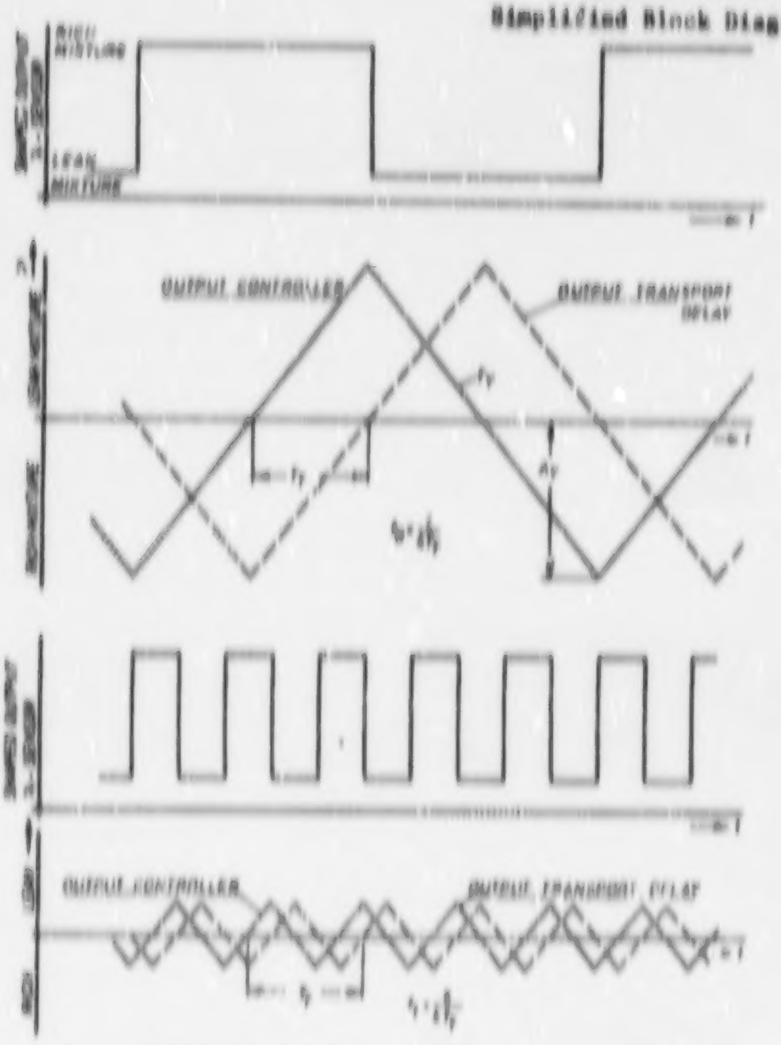


Figure Bosch-5

Frequencies of Closed Loop Operation

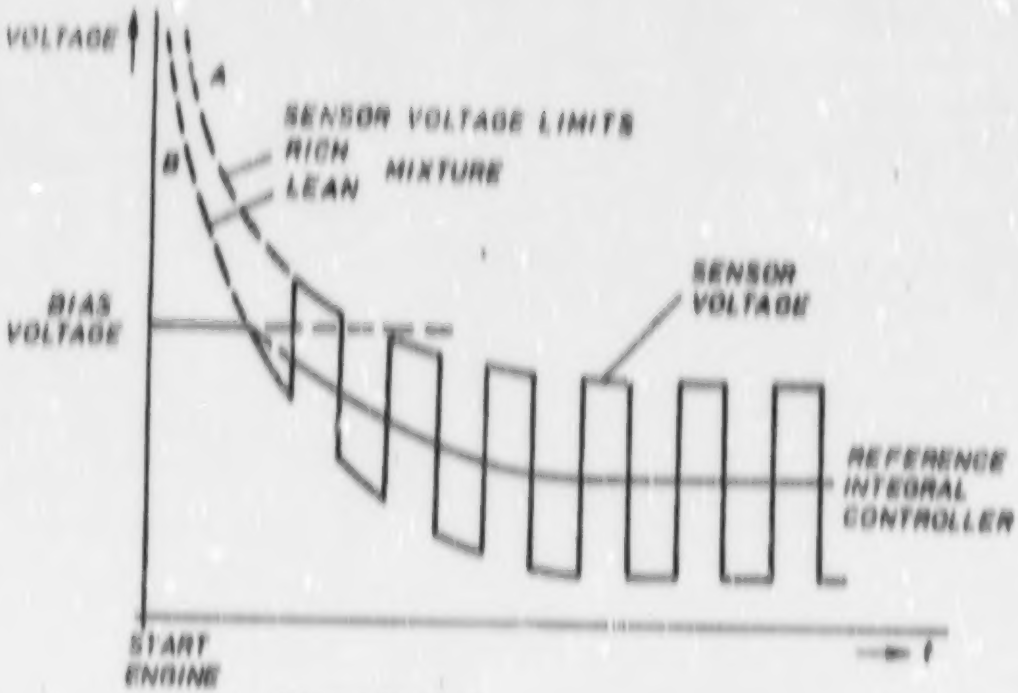

VOLTAGE
A
B
SENSOR VOLTAGE LIMITS
RICH
LEAN
MIXTURE
BIAS VOLTAGE
SENSOR VOLTAGE
REFERENCE INTEGRAL CONTROLLER
START ENGINE
t

Figure Bosch-6
Initialization of the Closed Loop

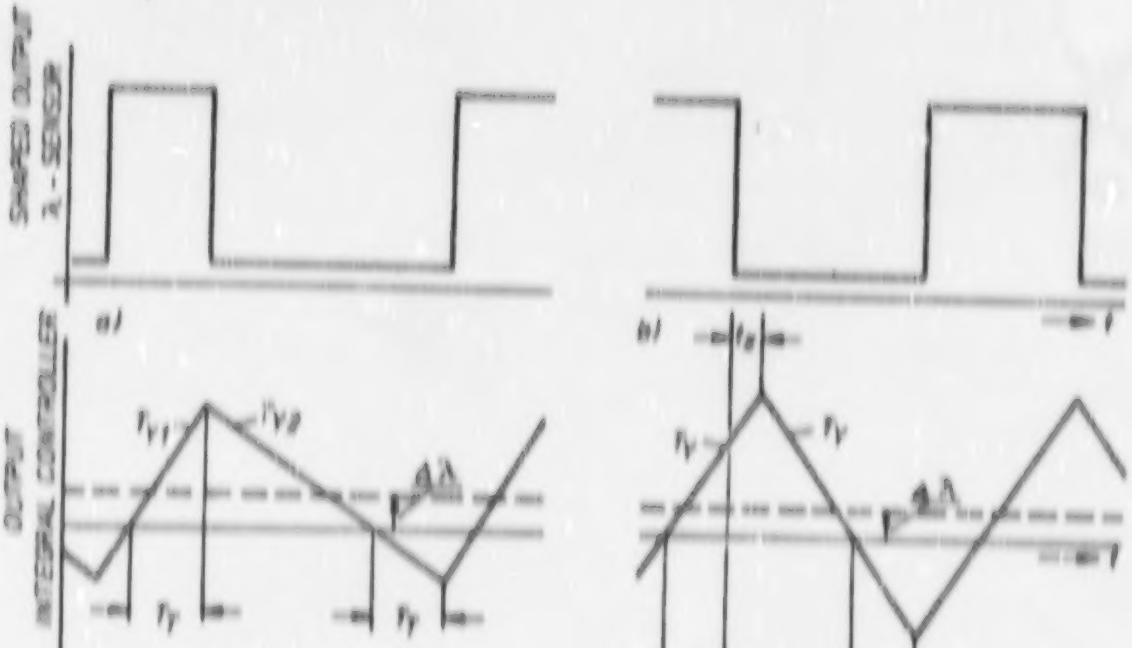

SHAPED OUTPUT λ-SENSOR
OUTPUT INTEGRAL CONTROLLER
a)
b)
t
t_{V1}
t_{V2}
Δλ
t_T
t_V
t_z
Δλ
t_T
t

Figure Bosch-7
Reference Adjustment

7.2.3. Dresser

Dresser Industries is a multi-divisional company which produces a variety of products including gas station pumps, tools, safety valves, and oil drilling equipment. Since 1970 Dresser has been involved in the development of a sonic carburetor known as the "Dresserator". Dresser felt the potential for the carburetor system, which was formerly under development at Stanford Research Institute, was sufficient to allow them to eventually obtain licensing fees from the automobile industry for its use.

The Dresser concept is an attempt to achieve fine fuel atomization over a wide range of operating conditions by maintaining a choked flow condition in the carburetor throat. By metering fuel upstream of the throat, the fuel must pass through the shock wave that occurs when the flow goes sub-sonic in the diffuser which is located downstream of the throat. The extremely fine droplet sizes reportedly created by the Dresserator (10 micron diameter) allow uniform air-fuel ratios (A/F) to be achieved during warm-up and transient conditions that cause A/F ratio variability problems with conventional carburetors. The wall wetting that occurs with conventional carburetors is less of a problem for the Dresserator. The coarser droplet size and heavier wall wetting that is characteristic of a conventional carburetor results in significant variations in air fuel ratio from cylinder-to-cylinder and from one cycle to the next cycle (successive intake charges for the same cylinder). To prevent lean misfire in a conventionally carbureted engine, this is counteracted by richening up the overall mixture so that the lean cylinders are not too lean. This has prevented the achievement in practice of the theoretical benefits of lean (18-19:1 A/F ratio) operation.

The achievement of sonic flow in a carburetor is not a new accomplishment. Conventional carburetors experience sonic conditions at idle and extremely light load operation when the ratio of manifold to ambient pressure is less than 0.528. The Dresser carburetor, however, maintains sonic conditions over most of the engine's operating range including modes where intake manifold pressure approaches ambient pressure. This is accomplished by the variable area, converging-diverging geometry of the Dresserator. Figure Dresser-1 is a schematic of the Dresserator geometry. Movement of a slider between two fixed jaws accomplishes the throat area changes necessary as the engine's air requirement changes. Previous versions of the Dresserator have employed moveable jaws without a slider and annular geometry with a vertically moveable cone to vary throat area. Figure Dresser-2 is a prototype Model III Dresserator completely assembled.

To regulate the fuel flow rate Dresser has relied in the past on a low pressure metering technique. This system increased the fuel pressure during cold start to provide the needed enrichment. This system worked fairly well but was handicapped to some degree by the cost of the pump and regulating device required. The sonic carburetor design is compatible with virtually any type of fuel metering method, and Dresser has devoted a lot of attention in the past year to studying alternate systems. These systems include: vacuum (float fed), electronically controlled pressure metering, and electronically modulated, float fed models. Most of this work has been done on the Model III units.

Three fundamental operating modes are forseen by Dresser for their sonic carburetors. These are:

a. Very lean, 18-19:1 air-fuel ratio
b. Stoichiometric, open loop with 3-way catalyst
c. Stoichiometric; closed loop with oxygen sensor,
   3-way catalyst

No emission data has been reported yet by Dresser for the 3-way catalyst modes but they have reached an agreement with Engelhard to work together

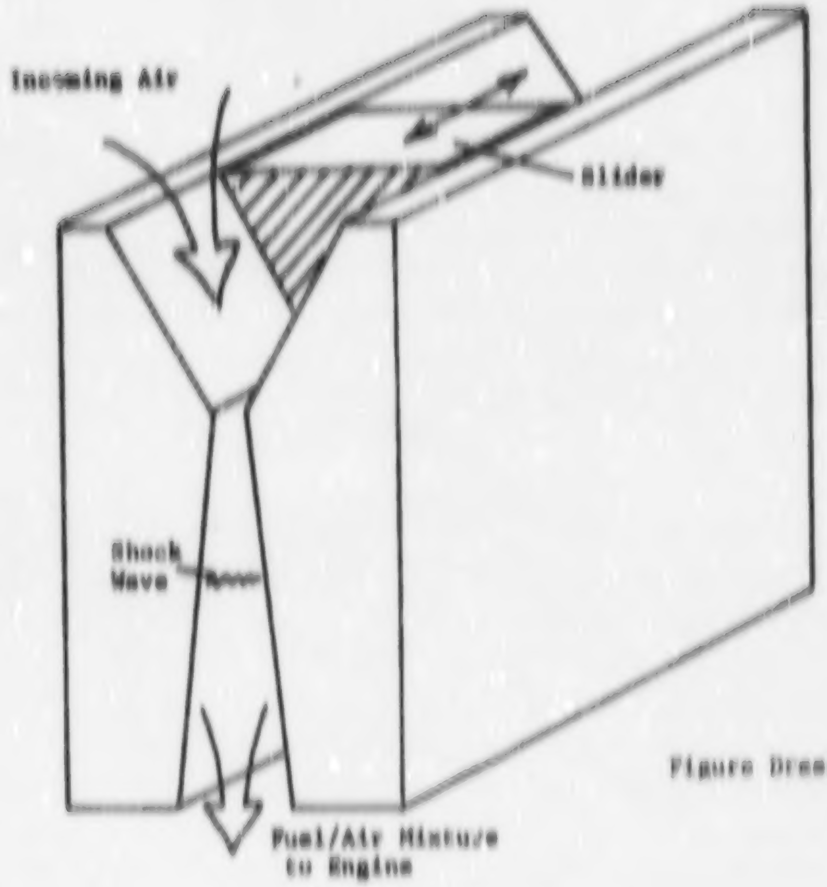

Incoming Air
Slider
Shock Wave
Fuel/Air Mixture to Engine

Figure Dresser-1

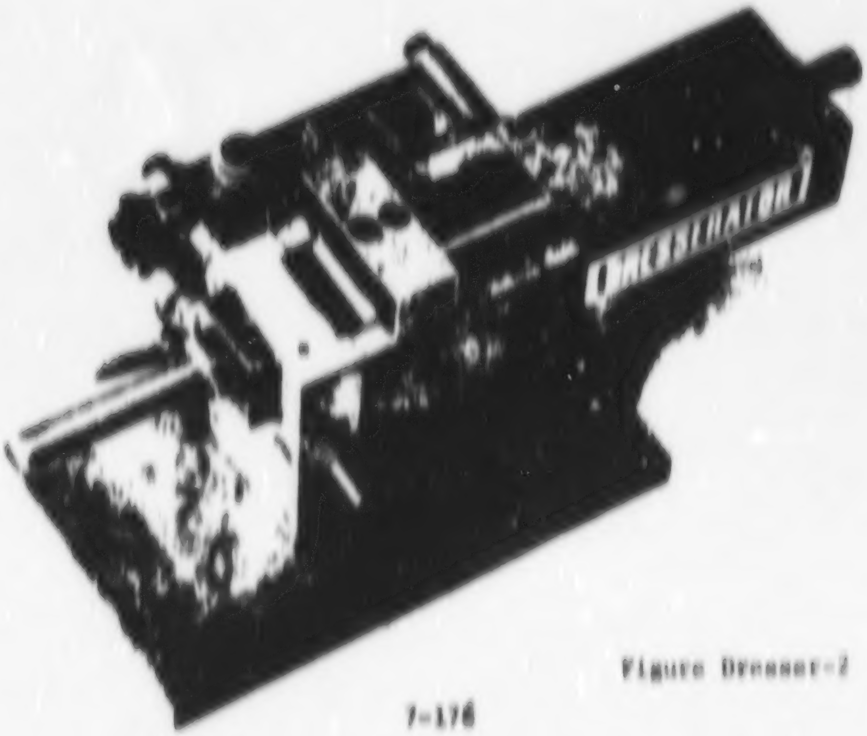


Figure Dresser-2

on this concept. It is understood that the open loop stoichiometric mode will be the primary objective for the initial phase of this work.

Dresser has a licensing agreement with Ford and Holley Carburetor Division of Colt Industries. The Ford arrangement has been in effect for several years. Ford has evaluated Dresser supplied units in the past, but most of Ford's work has been directed at developing their own version of a sonic carburetor. Ford has utilized electronically controlled fuel metering on their most recent units. Dresser reported that one of these units had been selected by Ford for 1979 model year introduction but was later shelved in favor of a less expensive, non-sonic, unit. The sonic unit was Ford's "D" body which resembles the Dresser Model II pivoting jaw unit. This Ford sonic unit used two electronically controlled injectors and was intended for use with a 3-way catalyst system. This system was targeted at the 1.0 NOx level.

Holley is working on a float fed unit which incorporates compensation features for enrichment during cold start, acceleration and large throttle openings. A unit incorporating these features was evaluated in a contract between Holley and EPA. This was a Model III unit and it was mounted on a 1975 California model Dodge Dart. The emission performance of the vehicle in the baseline condition and with the sonic carburetor is shown in Table Dresser-1. When the sonic carburetor was added, the air injection system was removed.

Table Dresser-1

1975 Dodge Dart, oxidation catalyst, EGR
Three Test Average for Each Case

System	HC	CO	NOx	MPG_u	MPG_h
Baseline	0.53	2.6	1.0	16.0	22.6
Sonic carburetion*	0.41	6.4	1.0	15.1	21.2
Sonic carburetion**	0.47	5.3	1.2	15.9	23.3

* Test results at Holley
** Test results at the EPA laboratory in Ann Arbor, MI.

Dresser reported that they have outfitted three small cars with sonic carburetors. These were two Capris, a 2800 cc V-6 and a 2600 cc V-6, and a 2000 cc 4 cylinder Triumph. Only steady state emissions and fuel economy data were presented but these appeared to show very significant emission reductions for the Capris with fuel economy equivalent to the baseline vehicles. Very limited data was provided for the Triumph, but the fuel economy was claimed to have been improved by 30%, according to Dresser.

Dresser reported the start of a program to build, evaluate, and ultimately market a retrofit model. This would be a float fed Model III unit using constant depression fuel metering. Dresser feels that they can provide a 10% to 15% gain in fuel economy on a retrofit basis.

Progress and Problems

The results to date from a vehicle equipped with a Dresser carburetor that had the subsystems generally thought to be necessary in a practical system (cold start enrichment, acceleration enrichment and power enrichment) have not been significantly better (in fact they have been somewhat worse) than the results from a conventional system. With the great interest being shown now in feedback control of conventional carburetion, it appears that systems employing the Dresser principle will have to show improvements in emissions and fuel economy over and above that demonstrated to date before the system will become widely used.

The Dresser principle may offer some potential if operated in a feedback mode, due to the possibility that the air-fuel mixing may be better than with conventional systems. However, data are not now available to show this. A feedback Dresser carburetor may receive significant competition from single-point feedback fuel injection systems in the future.

7.2.4. Engelhard

7.2.4.1. Systems Under Development

Virtually the entire Engelhard submission was devoted to the testing and development of monolithic and pelleted 3-way catalysts. The efforts included studies of 1) space velocity effects, 2) noble metal loading effects, 3) Pt/Rh ratio effects, 4) conversion efficiency deterioration as related to feedgas conditions, 5) conversion efficiency deterioration as a function of fuel contaminant levels, and 6) catalyst regeneration.

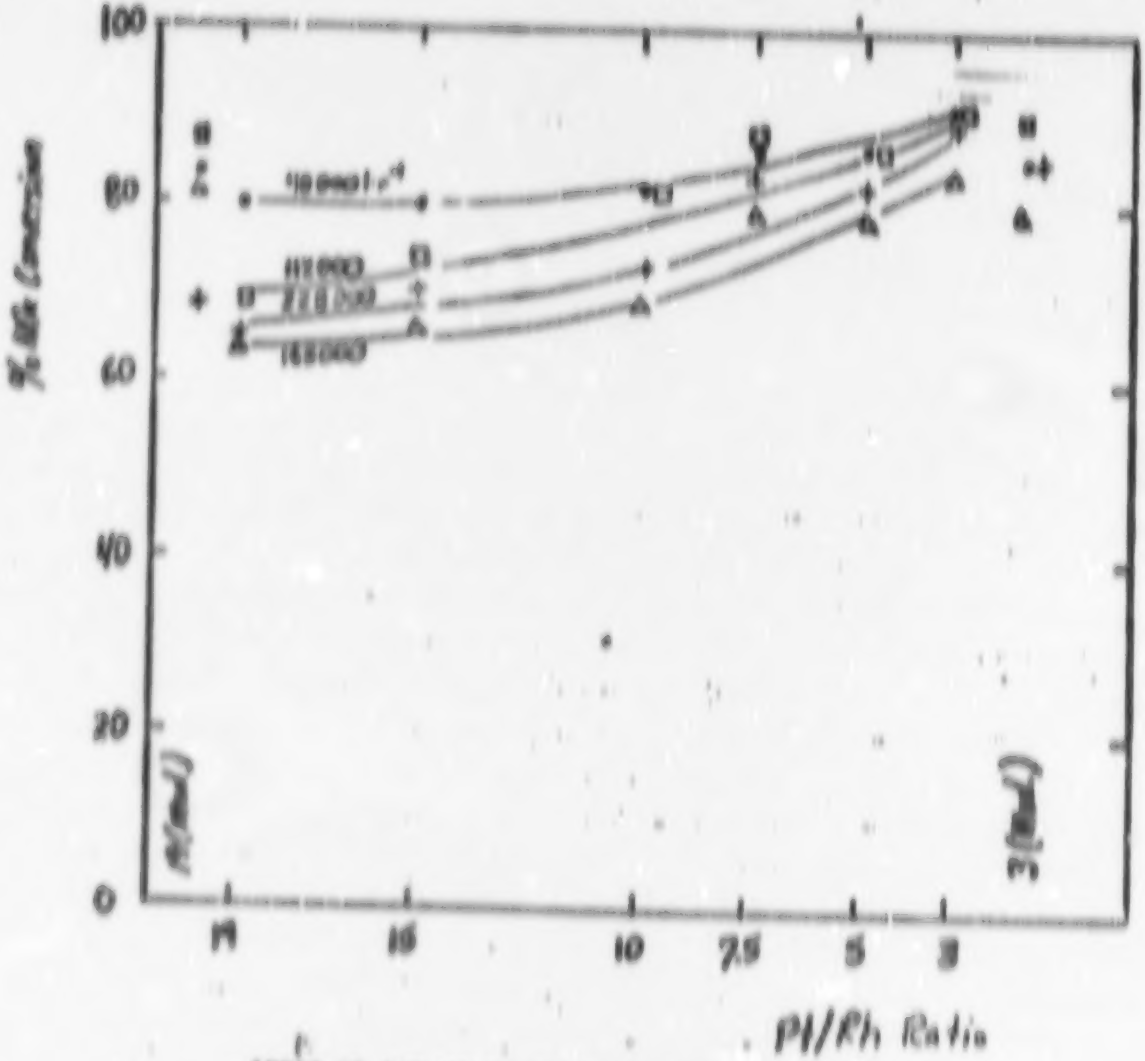
Monolithic 3-Way Catalysts

Figures Engelhard-1 and Engelhard-2 show the effects of space velocity and Pt/Rh ratio on NOx conversion efficiency. Though not stated by Engelhard, these efficiencies apparently are gross NOx conversion, and neglect the formation of ammonia. Ammonia formation however, may be low at stoichiometry. NOx efficiency was increased by reducing the space velocity (or increasing catalyst volume) and by reducing the Pt/Rh ratio. It should be noted that increased catalyst volumes at mine-mix Pt/Rh ratios (∿ 19/1) can provide nearly equivalent gross NOx conversion at 25,000 miles as smaller catalyst volumes at much lower Pt/Rh ratios. The 19 (mod) and 3 (mod) points apparently indicate modified catalyst formulations. Engelhard did not discuss these points; however, NOx conversion of the 19/1 Pt/Rh catalysts are equivalent to the 3/1 Pt/Rh catalysts when tested at 500°C inlet temperature. At 600°C inlet temperature, the 19 (mod) results are much like the mine-mix catalysts without this unidentified modification.

The importance of Pt/Rh ratio for monoliths is also shown in Figures Engelhard-3 and Engelhard-4. Over 20% difference in maximum NOx conversion at 25,000 miles is shown between the lowest and highest Pt/Rh ratios. Figure Engelhard-3 also shows the relationship of crossover

Figure Engelhard-1

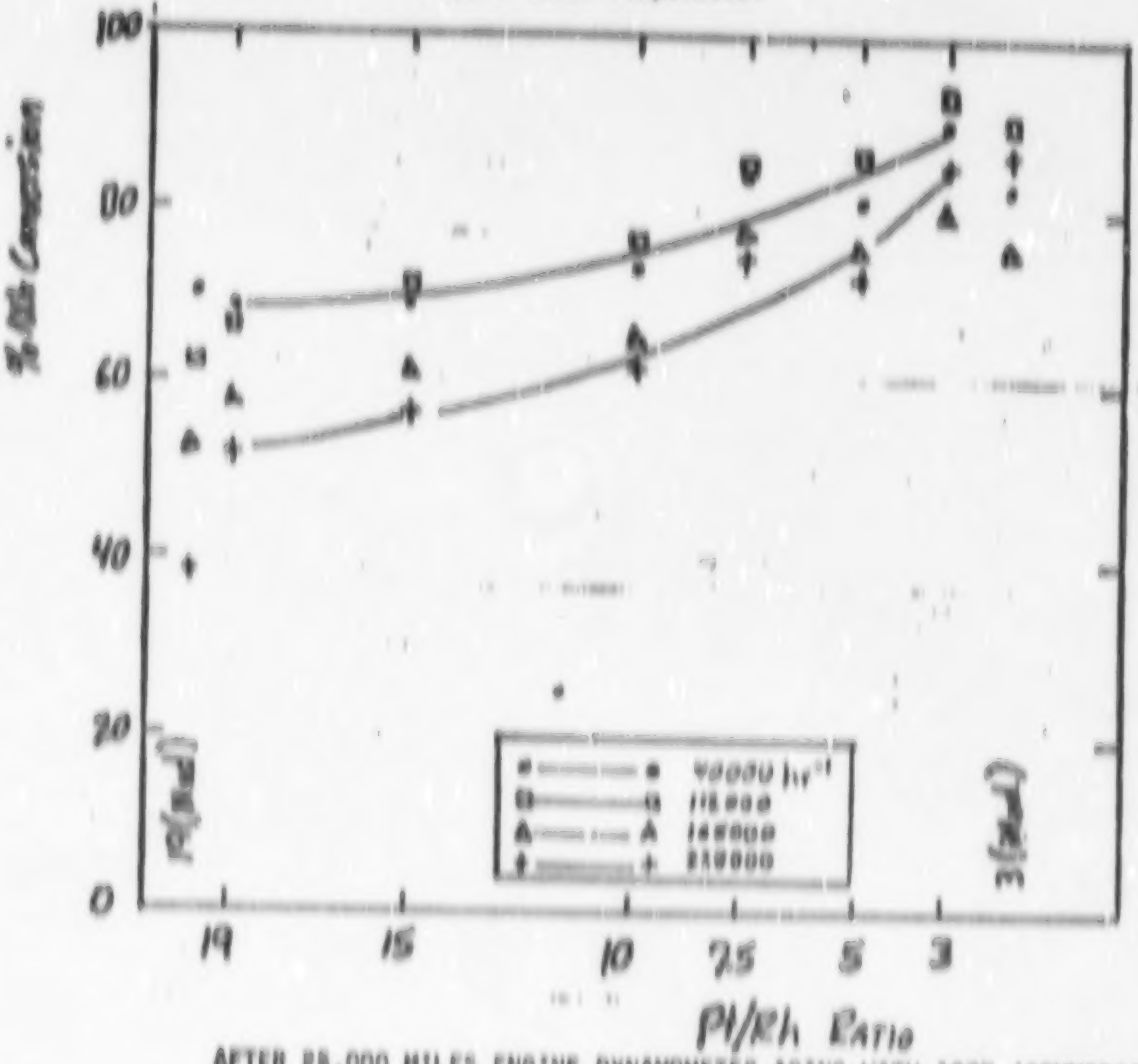
Effects of Space Velocity and Pt/Rh Ratio
- 500°C Inlet Temperature



AFTER 25,000 MILES ENGINE DYNAMOMETER AGING WITH
1977 (COMMERCIAL FUEL)

NOx CONVERSION AS A FUNCTION OF Pt/Rh RATIO
AT FOUR SPACE VELOCITIES, 500 M.V., 500°C
ENGINE DYNAMOMETER
SIX Pt/Rh RATIOS 19/1 → 3/1 PLUS 19/1
(Mod.) and 3/1 (Mod.)

Figure Engelhard-2
Effects of Space Velocity and Pt/Rh Ratio
@ 600°C Inlet Temperature



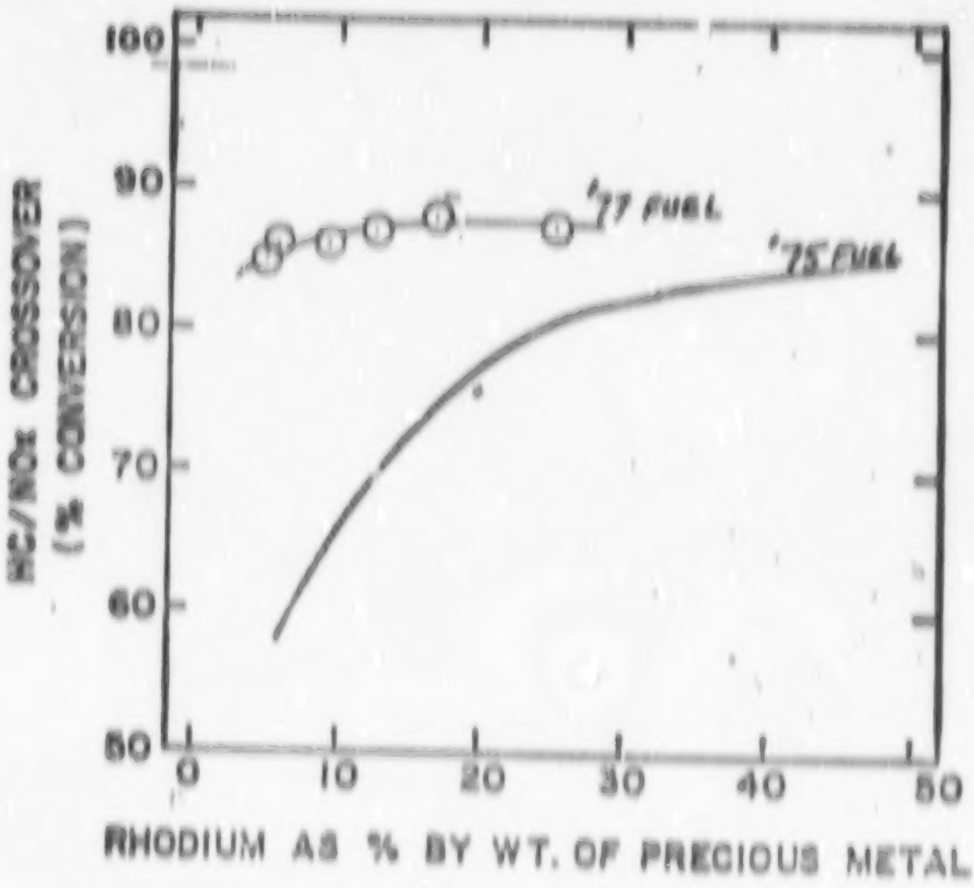
AFTER 25,000 MILES ENGINE DYNAMOMETER AGING WITH 1977 (COMMERCIAL) FUEL

NO_x CONVERSION AS A FUNCTION OF Pt/Rh RATIO
AT FOUR SPACE VELOCITIES, 500 M.V., 600°C
ENGINE DYNAMOMETER
SIX Pt/Rh RATIOS 19/1 → 3/1 PLUS 19/1
(Mod.) and 3/1 (Mod.)

Figure Engelhard-3

HC/NOx CROSSOVER

After 5,000 miles aging. Evaluated on Engine Dynamometer at 1600 RPM, 10-11" manifold vacuum, 620°C inlet temperature, and VHSV = 112,000 All catalysts loaded to 30 gm/cu. ft.



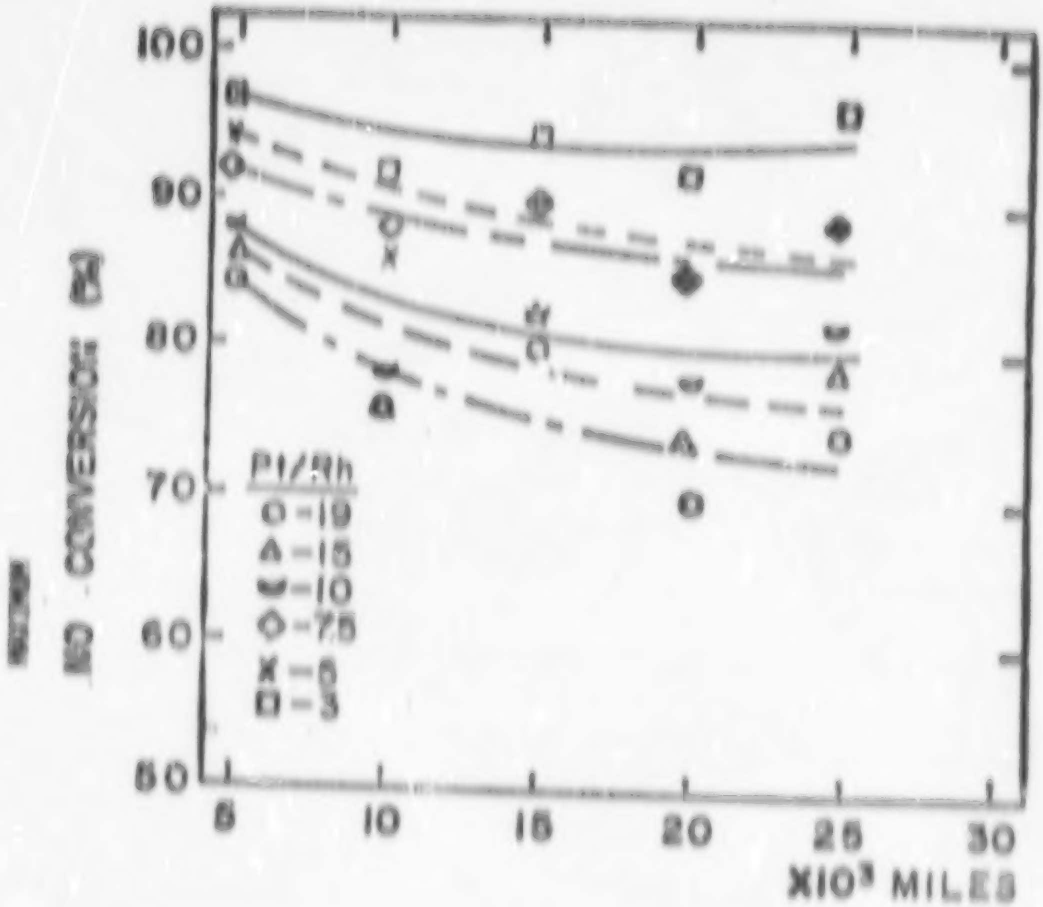
'77 Fuel = Commercial Fuel

'75 Fuel = 1975 Fuel (0.025 g/gal Pb)

Figure Engelhard-4

TWC CATALYST EFFICIENCY VS. DURABILITY MILEAGE

EVALUATION ON ENGINE DYNAMOMETER AT 1600 RPM, 10-11" MANIFOLD VACUUM,
620°C INLET TEMPERATURE AND VHSV=112,000



Fuel 1977

efficiency (the maximum conversion efficiency for the simultaneous conversion of all three pollutants). The crossover efficiency is later illustrated in Figure Engelhard-8 and is a very important indicator of 3-way catlyst performance. The crossover efficiency of Engelhard catalysts is generally limited by HC and NOx, but this is not true of all catalysts as CO and NOx are limiting in some cases.

The effect of Pt/Rh ratio on maximum HC efficiency is seen in Figure Engelhard-5. The Pt/Rh ratio did not affect the maximum HC efficiency. It should be noted that only 5,000 miles were accumulated on the catalysts in Figure Engelhard-5 as opposed to 25,000 miles on the catalysts in Figures Engelhard-1, 2, and 4. Engelhard reported that the accumulation of 5,000 miles on the 1975 certification-type fuel (.025 gm/gal Pb) yielded more catalyst deterioration than the accumulation of 25,000 miles on 1977 certification-type fuel (less than 0.005 gm/gal Pb). Sulfur and phosphorus levels of the fuels were 250-550 ppm sulfur and less than 1 ppm phosphorus.

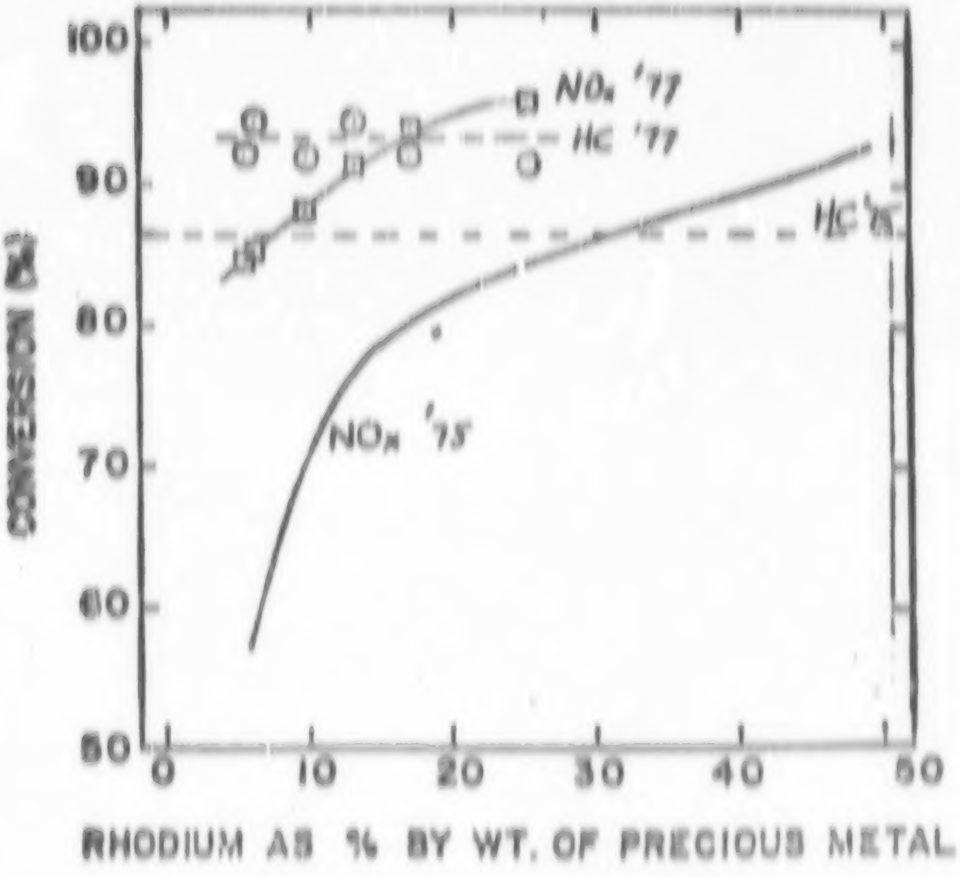
The effects of noble metal loading are shown in Figures Engelhard-6 and Engelhard-7 for the TWC-19 catalyst (11/1 Pt/Rh ratio). The loadings were reduced to 40% of the original (unspecified) loading. Both the maximum HC and NOx efficiencies were always within about 10% of the highest values at all loadings. Further mileage accumulation, higher catalyst temperatures, or higher fuel contaminant levels could change this apparent lack of change in maximum HC or NOx efficiency with reduced noble metal loadings. Crossover efficiencies were not given for the TWC-19C.

Studies were conducted to determine the relative conversion efficiencies versus air-fuel ratio which resulted from high temperature aging (at 1000°F for 24 hours) under nearly stoichiometric conditions (0.8% oxygen), highly oxidizing conditions, and highly reducing conditions. The conversion efficiencies of HC and NO were generally higher when aged at high temperature at stoichiometry or under oxidizing conditions, and lower when aged under reducing conditions. This ranking of efficiency

Figure Engelhard-5

MAXIMUM CONVERSION OF HC OR NOx AFTER 5000 MILES AGING

Evaluation on Engine Dynamometer at 1600 RPM, 10-11" manifold vacuum, 620°C inlet temperature and VHSV = 112,000. All catalysts loaded at 50 gm/cu. Ft.



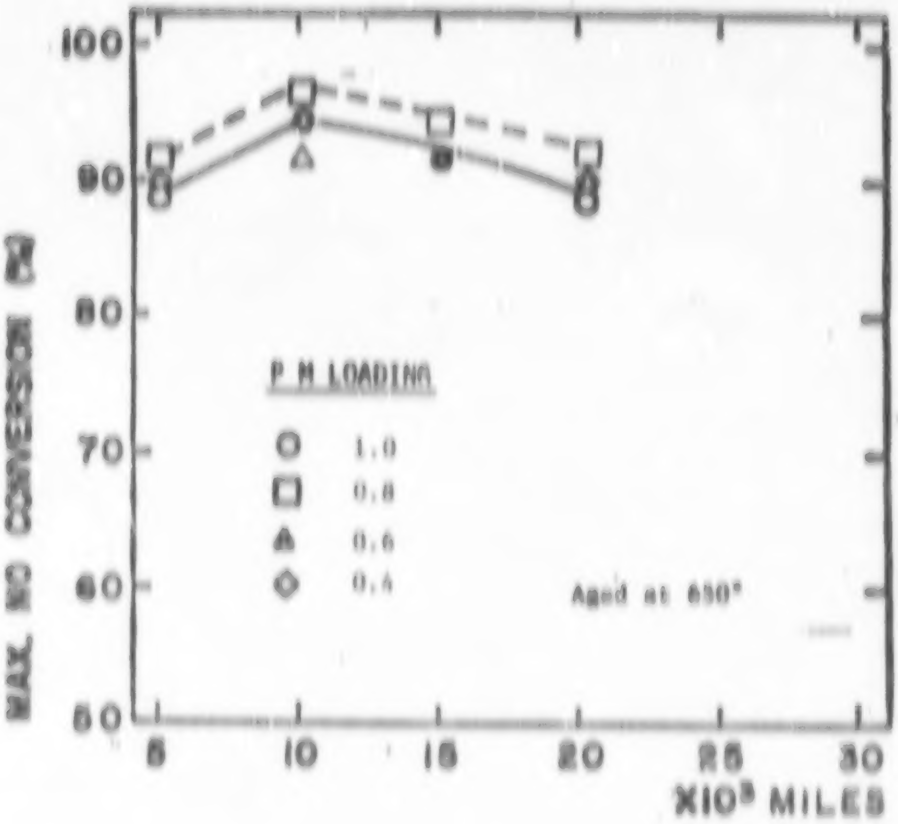
NOx '77 and HC '77 = 1977 Commercial Fuel

NOx '75 and HC '75 = 1975 Fuel (0.025 g/gal Pb)

Figure Engelhard-6

TWC CATALYST EFFICIENCY VS. DURABILITY MILEAGE

TWC 19C,600 °C,112,000 VHSV

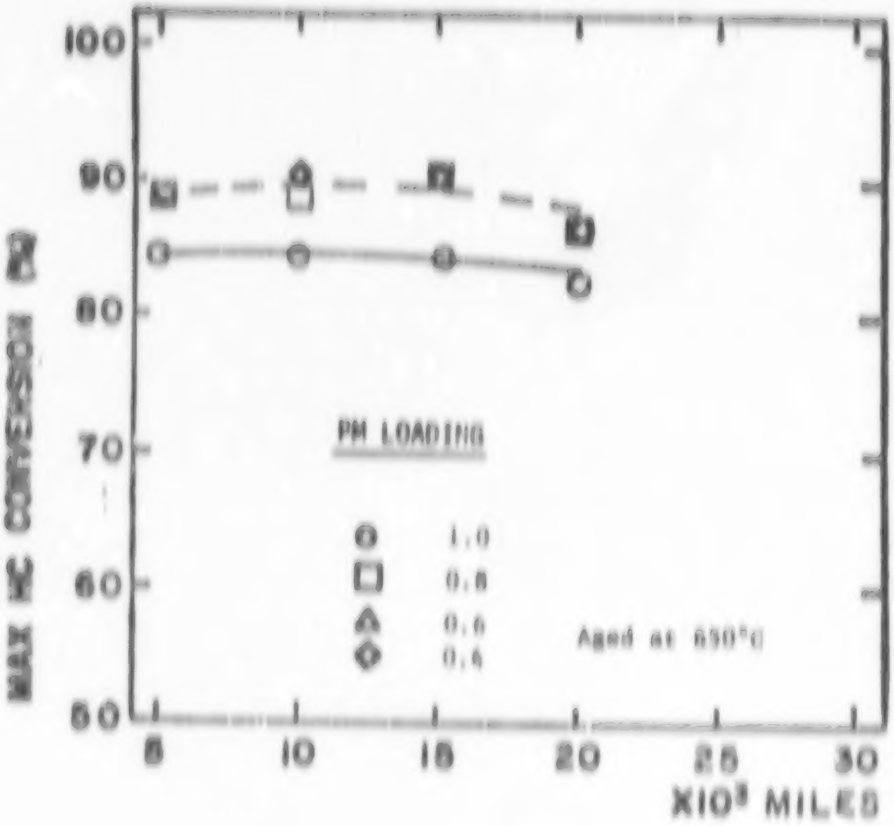


Fuel 1977

Figure Engelhard-7

TWC CATALYST EFFICIENCY VS. DURABILITY MILEAGE

TWC I9C,600 °C,112,000 VHSV



Fuel 1977

versus aging condition was reversed for CO. The conversion of NOx to ammonia was generally minimized when the catalyst was aged under reducing conditions and generally maximized when aged under oxidizing conditions for an after aging air-fuel ratio test range of 14.2 to 14.7. These tests also suggest that substantial losses in surface area of the washcoat or noble metals of the TWC-9 catalysts did not result from these high temperature excursions.

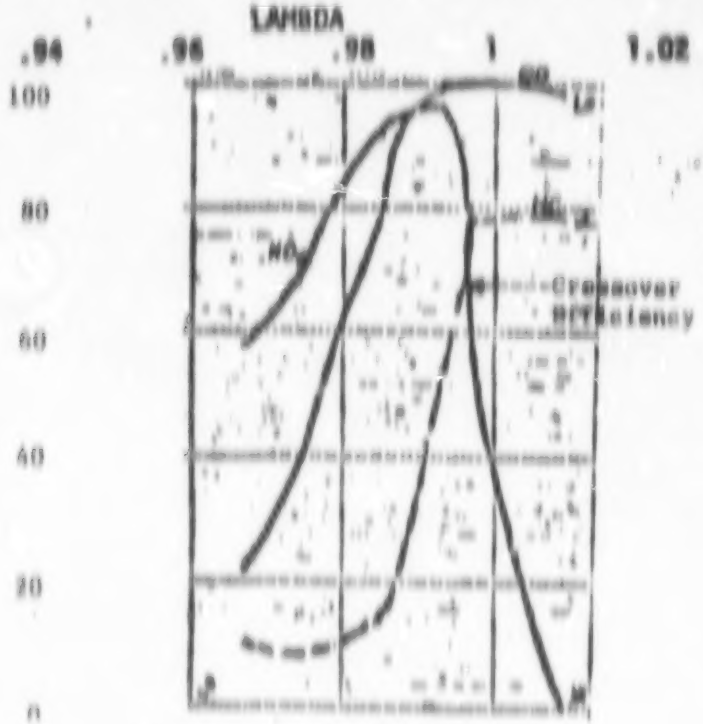
Catalyst regeneration was accomplished by disconnecting one spark plug wire which caused the catalyst temperature to increase. Apparently, the high catalyst temperature caused some of the catalyst contaminants to be released. NO efficiency was greatly increased by the regeneration, HC efficiency was slightly increased, and CO efficiency appeared to be slightly reduced.

Pelleted 3-Way Catalysts

The effects of two different space velocities are shown in Figures Engelhard-8 to Engelhard-11 for the TWC-13B catalyst (10/1 Pt/Rh). The reduction in space velocity from 228,000 to 112,000 per hour did not show much of a benefit on the operational 3-way catalyst window. The effect of noble metal loading is also seen when Figures Engelhard-8 and Engelhard-9 are compared to Figures Engelhard-10 and Engelhard-11. The noble metal loadings were 15 gm/cu. ft. in the first two figures and 45 gm/cu. ft. in the next two figures. The crossover efficiencies of HC and NOx increased somewhat with increased loading, but of equal importance is the increased window width (at 60% efficiency) with higher loadings. Engelhard does not like to place too much emphasis on window width because of the difficulties in obtaining accurate values of λ. EPA agrees that accurate measurements of HC, CO, NOx, CO_2 and O_2 are needed, but EPA also believes that window width is an important parameter in the evaluation of low mileage catalysts, particularly when the evaluations are done on engines with closed loop air-fuel metering systems.

Figure Engelhard-8

TWC-13B with 15gm/cu. ft. Loading at a Space Velocity of 112,000 per Hour



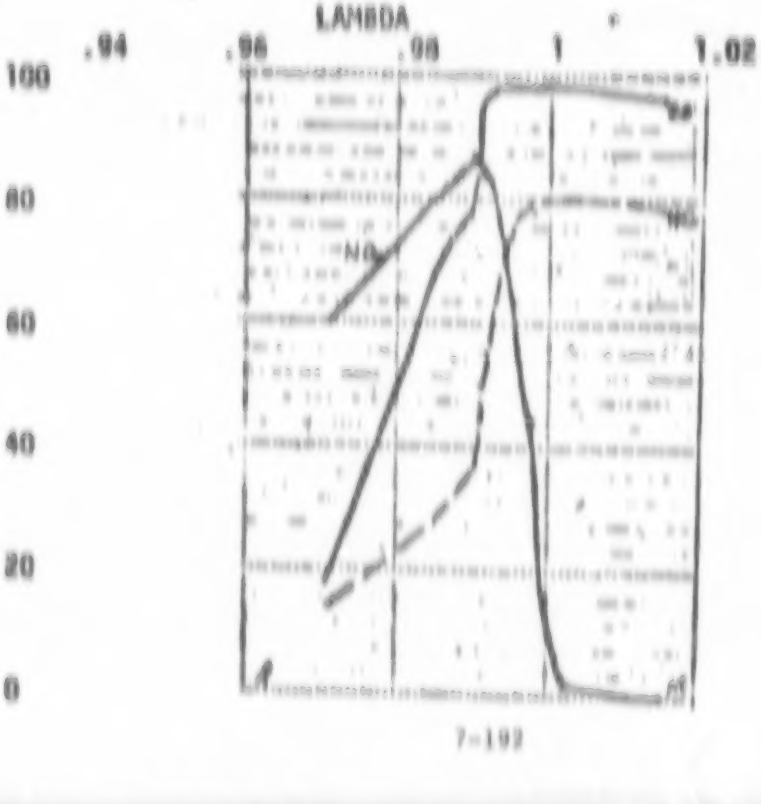
Operating Conditions:

Inlet Temperature = 600°C
Manifold Vacuum = 12 in. Hg
MPH = 23
Sensor Controlled Aging
Aged 5,000 Miles

1975 Durability Fuel
Pb = .020-.025 g/gal.

Figure Engelhard-9

TWC-13B with 15gm/cu. ft. Loading at a Space Velocity of 228,000 per Hour



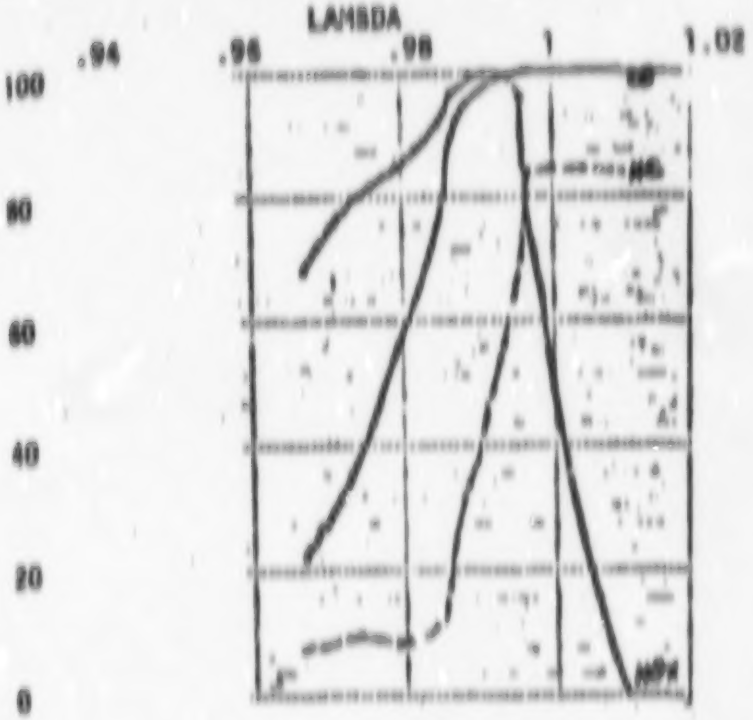
Operating Conditions:

Inlet Temperature = 700°C
Manifold Vacuum = 6 in. Hg
MPH = 39
Sensor Controlled Aging
Aged 5,000 Miles

1975 Fuel

Figure Engelhard-10

TWC-13B with 45gm/cu. ft. Loading At a Space Velocity of 112,000 per Hour



Operating Conditions:

Inlet Temperature = 600°C

Manifold Vacuum = 12 in. HG

MPH = 23

Sensor Controlled Aging

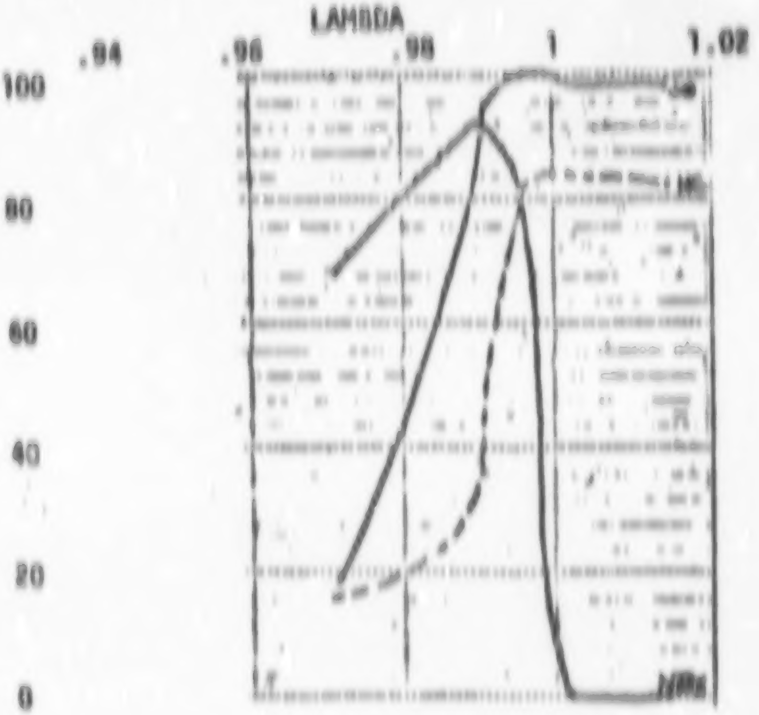
Aged 5,000 Miles

1975 Durability Fuel
Pb = .020-.025 g/gal.

Reproduced from best available copy.

Figure Engelhard-11

TWC-13B with 45gm/cu. ft. Loading at a Space Velocity of 228,000 per Hour



Operating Conditions:

Inlet Temperature = 700°C

Manifold Vacuum = 6 in. Hg

MPH = 39

Sensor Controlled Aging

Aged 5,000 Miles

1975 Fuel

Figure Engelhard-12 shows the effect of Pt/Rh ratio on the crossover efficiency for HC and NOx for the TWC-18 catalyst. At the minimum Pt/Rh ratio, the pellets showed poorer efficiency than the previously mentioned monoliths, but at higher Pt/Rh ratios near mine-mix, the pellet was superior in crossover efficiency when compared to the monoliths in Figure Engelhard-3. The respective aging conditions of the catalysts were not discussed by Engelhard, and may have been different.

It should be noted that the crossover efficiencies are warmed-up efficiencies and do not necessarily represent FTP conversion efficiency. Although the pellet may have higher warmed-up efficiency, the monolith may still have better FTP efficiency because of better light off characteristics.

As a final comparison, the best reported pelleted 3-way catalyst had about 82% HC/NOx crossover efficiency and the best reported monolith also had about 82% HC/NOx crossover efficiency. Both of these results are at 5,000 miles on the 1975 fuel but the precise aging conditions may have been different. The monolith used a mine-mix Pt/Rh ratio. The Pt/Rh ratio of the TWC-13B pellet was 10/1. The monolith was the TWC-9D. The TWC-9D is considered by EPA to be inferior to the TWC-19 and TWC-16 series monolithic catalysts from Engelhard, particularly for net NOx efficiency. Efficiency plots were not presented for either of those two catalysts.

Testing with the Holley Feedback Carburetor

Low mileage testing of a Pinto with a 2.3 litre engine, which used a Holley feedback carburetor, was conducted at Engelhard in a joint development effort between Holley and Engelhard. The vehicle was a 1976 model at 2750 pounds inertia weight (10.8 horsepower at 50 MPH) with an automatic transmission and did not use EGR or AIR. These test results are shown in Table Engelhard-1.

Figure Engelhard-12

CONVERSION CROSSOVER OF HC/NOx AND MAXIMUM CONVERSION OF HC OR NOx AFTER 5000 MILES AGING ON 1975 FUEL

EVALUATION ON ENGINE DYNAMOMETER AT 1600 RPM, 11"–13" MANIFOLD VACUUM, 600°C INLET TEMPERATURE AND VHSV = 112,000

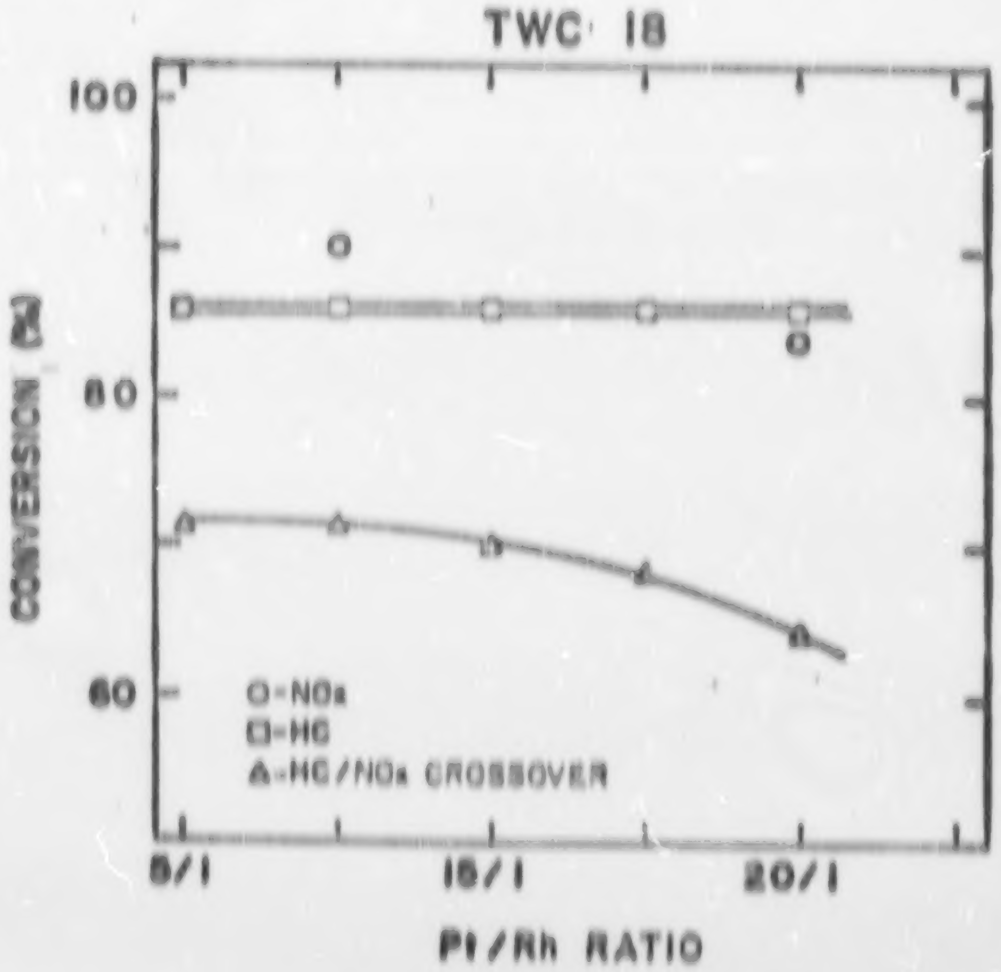


Table Engelhard-1

Testing of 2.3 litre Pinto

Catalyst	FTP Test Results (gm/mi) HC	CO	NOx	Catalyst Efficiency (%) HC	CO	NOx
None	1.15	9.84	5.27	--	--	--
TWC-9B	0.31	2.86	1.39	73.0	70.9	73.6
TWC-16	0.26	2.31	0.83	77.4	76.5	84.3

The TWC-9B accumulated 10,000 miles of AMA durability with fuel containing 0.020-0.024 gm/gal Pb (4-5 times as much Pb as used in the Engelhard 1977 certification-type fuel). The TWC-16 accumulated 9,800 miles with commercial unleaded fuel. Thus it appears for the TWC-9B catalyst that if the carburetor can maintain its stoichiometric calibration, conversion efficiencies of 70% or greater for all three regulated pollutants may be achieveable at 50,000 miles.

7.2.4.2. Durability Testing

Other vehicle testing reported by Engelhard used a Toyota Crown Mark II vehicle with a 2.0 litre engine and an automatic transmission. Vehicle test results were reported at 3000 pounds IW. Each of the two catalysts had been used on a vehicle that had accumulated 20,000 durability miles. The test results are shown in Table Engelhard-2.

Table Engelhard-2

Catalyst	Toyota Vehicle FTP Test Results HC	CO	NOx	Fuel Economy MPG$_U$
Dummy	2.07	14.01	3.50	16.7
TWC-16	0.38	2.18	0.47	17.2
TWC-9B	0.40	2.36	0.55	16.9

The FTP conversion efficiencies were over 80% for all three pollutants for both catalysts at 20,000 miles.

7.2.4.3. Progress and Problem Areas

Vehicle tests conducted by Engelhard, and by others using Engelhard catalysts, have shown that a great deal of progress has been made in increasing the crossover efficiency and window width of 3-way catalysts. Based on the Engelhard submission, and submissions from vehicle manufacturers, Engelhard appears to be a leader in 3-way catalyst technology.

Problems for Engelhard include the lack of data on the effects of MMT and 0.03% sulfur in the fuel and the lack of complete studies of unregulated emissions from their 3-way catalysts.

7.2.5. Ethyl Corporation

The Ethyl Corporation continues to develop the Turbulent Flow System (TFS) in pursuit of an non-catalytic emission control system. During the past year, Ethyl has concentrated on Turbulent Flow Manifold (TFM) modifications and improvements, the effects of EGR with TFS, heat conservation and lean reactor development, compression ratio, TFS in combination with an electronic spark advance system, port liners, and extended system durability up to 100,000 miles.

The significance of the TFS continues to be the use of heat conservation and lean reactor technology rather than operation of an engine solely with lean calibrations.

Ethyl continued to refine and improve their TFM during the past year. Results from two vehicles equipped with the TFM indicate that carburetor production tolerances and misadjusted idle mixtures have no detrimental effect on the cylinder to cylinder air-fuel spread. Work also continues on refining the air-fuel distribution capabilities, increasing heat transfer to the conditioning chamber for improved cold start operation, and the effect of EGR introduction into the TFM.

Further work was conducted on the benefits of port liners, both individually and in combination with a lean thermal reactor. Ethyl's reactor work centered on the investigation of the emission reduction potential of three types of reactors: open, baffled, and a cored model. Their tests indicate that the cored reactor was superior under simulated transient conditions and further vehicle tests will be conducted using this reactor to confirm their results. Much of the previously mentioned testing was engine dynamometer testing rather than vehicle testing.

Ethyl reported work on a proprietary system which is an extension of their TFS. The development work was conducted on one of their previously reported lower inertia weight vehicles. The significance of this work lies in the demonstration of results indicating levels of 0.41 HC, 3.4 CO, 2.0 NOx are possible with a thermal, as opposed to a catalytic, aftertreatment system.

Results from these vehicles are shown in Table Ethyl-1 and compared to similar vehicles and 1977 model year vehicles.

Table Ethyl-1

Vehicle	IW	Trans	FTP Results (gm/mi) HC	CO	NOx	Fuel Economy MPG_u
Development #1	2500	M4	0.10	2.34	1.52	20.0
Baseline	2500	M4	3.29	25.10	2.34	22.8
Development #2	2750	A3	0.09	1.90	1.86	21.5
Baseline	2750	A3	2.42	37.59	2.24	23.7
Comparable Certification Vehicles						
1973-2bbl	2500	M4	1.9	22.0	1.9	22.4*
-2bbl	2500	A3	2.1	27.0	1.5	22.8*
-FI	2500	M4	2.4	23.0	1.7	23.0*
-FI	2500	M4	2.9	24.0	1.1	23.5*
1977-FI + TR + EGR + AIR	2750	M4	0.18	6.3	1.02	19.6
	2750	M4**	0.35	8.3	0.80	18.0
	2750	A	0.32	8.5	1.09	19.7
-FI + AIR + EGR	2750	A	1.00	8.5	1.31	18.7
	2750	M4	1.13	8.6	1.49	20.2

* 1973 Certification vehicle fuel economy originally measured on the 1972 FTP. Results adjusted to 1975 FTP equivalent by a factor of 1.045.

** High Altitude vehicle

This system may have potential for combination with other emission control techniques such as electronic spark advance, electronic EGR, etc. which could improve both NOx emissions and fuel economy.

Ethyl also reported on their continuing study of the effects of compression ratio on emissions and fuel economy. The study involved raising the compression ratio one unit on two different vehicles. The results indicate that the predictable composite fuel economy benefits of as much as 6.2% can be achieved at the expense of increased hydrocarbon emissions. Ethyl feels the use of exhaust port liners could keep this hydrocarbon increase to 6% for a one unit increase in compression ratio. Representative data for one of the vehicles are shown in Table Ethyl-2.

Table Ethyl-2

Effect of Port Liners and Compression Ratio on Emissions and Fuel Economy

1974 360 CID Plymouth Fury III
5000 lb Inertia Weight
TFS, Carter 4-Barrel Carburetor

Configuration	1975 FTP Emission (gm/mi) HC	CO	NOx	Fuel Economy (MPG) MPG_u	MPG_h	MPG_c	O.N. Req'd (FBRU)
8.0 CR + Exh. Port Liners	1.06	9.36	1.97	11.3	18.1	13.60	92
9.0 CR + Exh. Port Liners (Unadjusted Performance)	1.22	8.34	1.88	11.5	19.2	14.05	100
Same as above (Equal perf. to 8.0 CR)	1.18	6.98	1.69	11.8	19.7	14.40	-

Table Ethyl-2 shows higher HC emissions, higher octane requirement, lower CO, lower NOx, and improved fuel economy for the higher compression ratio case.

Table Ethyl-3*

Exhaust Emissions

1974 Dodge Coronet, Car #857
360 CID V-8 Engine
TFS with Exhaust Port Liners and Exhaust Reactors

Test Miles	1975 CVS Emissions, gm/mi HC	CO	NOx	Fuel Economy, MPG$_M$
		Phase I		
0	0.22	3.33	1.26	10.4
3,000	0.24	4.29	1.66	10.6
5,000	0.30	4.61	1.83	11.3
10,000	0.35	5.05	1.77	11.1
15,000	0.36	4.93	2.13	10.7
20,000	0.43	4.66	2.02	11.3
25,000	0.49	6.33	1.78	11.1
30,000	0.41	5.77	1.79	11.3
35,000	0.48	5.70	1.97	11.9
40,000	0.37	5.06	1.75	11.1
45,000	0.41	5.95	1.82	11.2
50,000	0.43	6.07	1.93	11.3
			Average	11.1
50,000-Miles Deterioration Factor	1.28	1.26	1.00	
		Phase II		
55,000	0.33	5.09	1.57	11.4
60,000	0.50	6.50	2.26	11.4
65,000	0.37	5.96	2.03	10.7
70,000	0.35	6.24	1.86	10.6
75,000	0.41	5.65	1.65	10.9
80,000	0.48	7.09	1.95	10.3
85,000	0.42	4.88	1.58	11.0
90,000	0.43	5.83	1.54	10.7
95,000	0.47	5.93	1.78	11.1
100,000	0.38	7.13	1.41	10.9
			Average	10.9

---

* Ethyl data reported in Status Report submission page VI-16

Ethyl extended the durability testing of the TFS vehicle which they reported last year. The extended mileage results were shown in Table Ethyl-3. Ethyl performed some maintenance based on emission results which is not allowed by EPA in official durability testing. On the other hand, according to Ethyl, the maintenance intervals for plug change and EGR system cleaning during the durability run were longer than that recommended by the original vehicle manufacturer. The methane and sulfate emissions as reported by Ethyl are shown in Table Ethyl-4. No mileage is specified for the methane results.

Table Ethyl-4

Sulfate Emissions

TFS-Lean Reactor Car
50,000 miles

	FTP Emissions, gm/mi				Fuel Economy, MPG	Percent Conversion H_2SO_4 *
	HC	CO	NOx	H_2SO_4		
FTP	0.43	6.07	1.93	0.021	11.3	1.0
Highway	0.18	3.49	2.59	0.013	18.8	1.0
Sulfate Cycle	NA	NA	NA	0.009	NA	0.6

* Based on 0.03% sulfur in test gasoline

Methane Emissions**

TFS-Lean Reactor Car

	FTP Emissions				Percent CH_4
	HC	CO	NOx	CH_4	
FTP, gm/mi	0.27	5.79	1.26	0.011	4.1
FTP Bags, gm					
Cold Transient	2.91	55.77	5.73	0.120	4.1
Hot Stabilized	0.43	9.63	4.28	0.025	5.8
Hot Transient	0.67	10.68	4.74	0.015	2.2

** Methane was measured using a Baseline Industries Gas Chromatograph - Series 1000 B.

Ethyl reported other proprietary development work that leads to the estimation that TFS in combination with other known emission control techniques could result in achievement of levels of 0.41 HC, 3.4 CO, 1.0 NOx or lower without catalytic aftertreatment. However, this system would initially be limited to smaller vehicles and not be available until model year 1981. This combination system's fuel economy remains to be evaluated.

Ethyl did not discuss their work on the control of particulate emissions and driveability of lean reactor equipped vehicles. Ethyl does not routinely use a driveability test that results in a quantifiable numerical rating. Vehicles are rated by a subjective procedure which, according to Ethyl, has resulted in vehicles considered by Ethyl to have commercial driveability also considered to be acceptable in drivability by some automotive manufacturers.

Ethyl's work with particulate traps has been concentrated on the non-domestic market and is centered on European, Australian, and other potential users of particulate trap technology.

7.2.6. Holley

The Holley Carburetor Division of Colt Industries has developed a feedback carburetor which will be used by Ford in the 1978 verification of their Pinto with a 2.3 litre engine for California. While Holley is known to be developing feedback carburetion for other engines also, their report to EPA primarily discussed an experimental Pinto with a 2.3 litre engine system.

The Holley system is relatively uncomplicated as shown in Figures Holley-1 and Holley-2. During warmed-up operation, the oxygen sensor output is compared to a reference signal in the ECU to yield an ECU output signal to the vacuum control valve. The vacuum control valve in turn modulates vacuum from the vacuum storage canister to the twin diaphrams in the carburetor. The variable air bleed has the potential to keep the system at stoichiometry during idle and off idle operation. The auxiliary main metering system provides for stoichiometry in the part throttle operating range. The auxiliary main metering circuit is a refinement of what previously was the power enrichment circuit, according to Holley.

The ECU output was said to be a square wave. The width of the square wave is variable and depends on the input from the oxygen sensor. The system runs in the open loop mode during both wide open throttle and engine warm-up conditions.

Holley indicated that an adjustment of the ECU can be made to maximize HC, CO, and NOx control by modifying the relationship of the ECU output to input. Additionally, circuit gains and time constants can be modified to achieve relatively uniform engine-out CO levels over the operational range of the engine. Figure Holley-3 shows that the Holley system can provide stable air-fuel metering under rich and lean conditions as well as at stoichiometry. Holley did not reveal which, if any, of these adjustments to the ECU will be required on a production vehicle.

Figure Holley-1

HOLLEY ELECTRONIC METERING CARBURETOR
THREE-WAY CATALYST APPLICATION

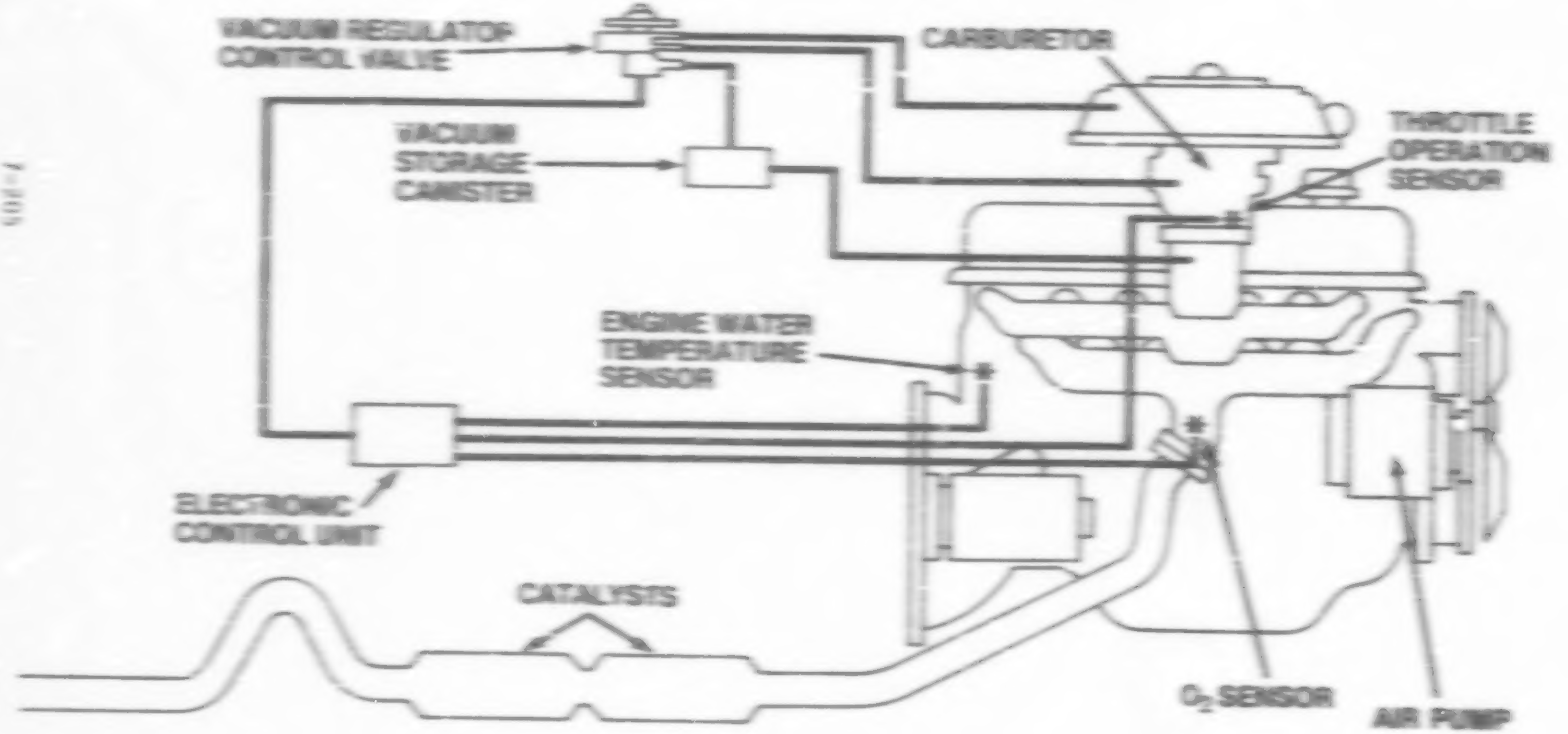

VACUUM REGULATOR CONTROL VALVE
CARBURETOR
THROTTLE OPERATION SENSOR
VACUUM STORAGE CANISTER
ENGINE WATER TEMPERATURE SENSOR
ELECTRONIC CONTROL UNIT
CATALYSTS
O2 SENSOR
AIR PUMP

Figure Holley-2

FEEDBACK CARBURETOR SCHEMATIC DRAWING

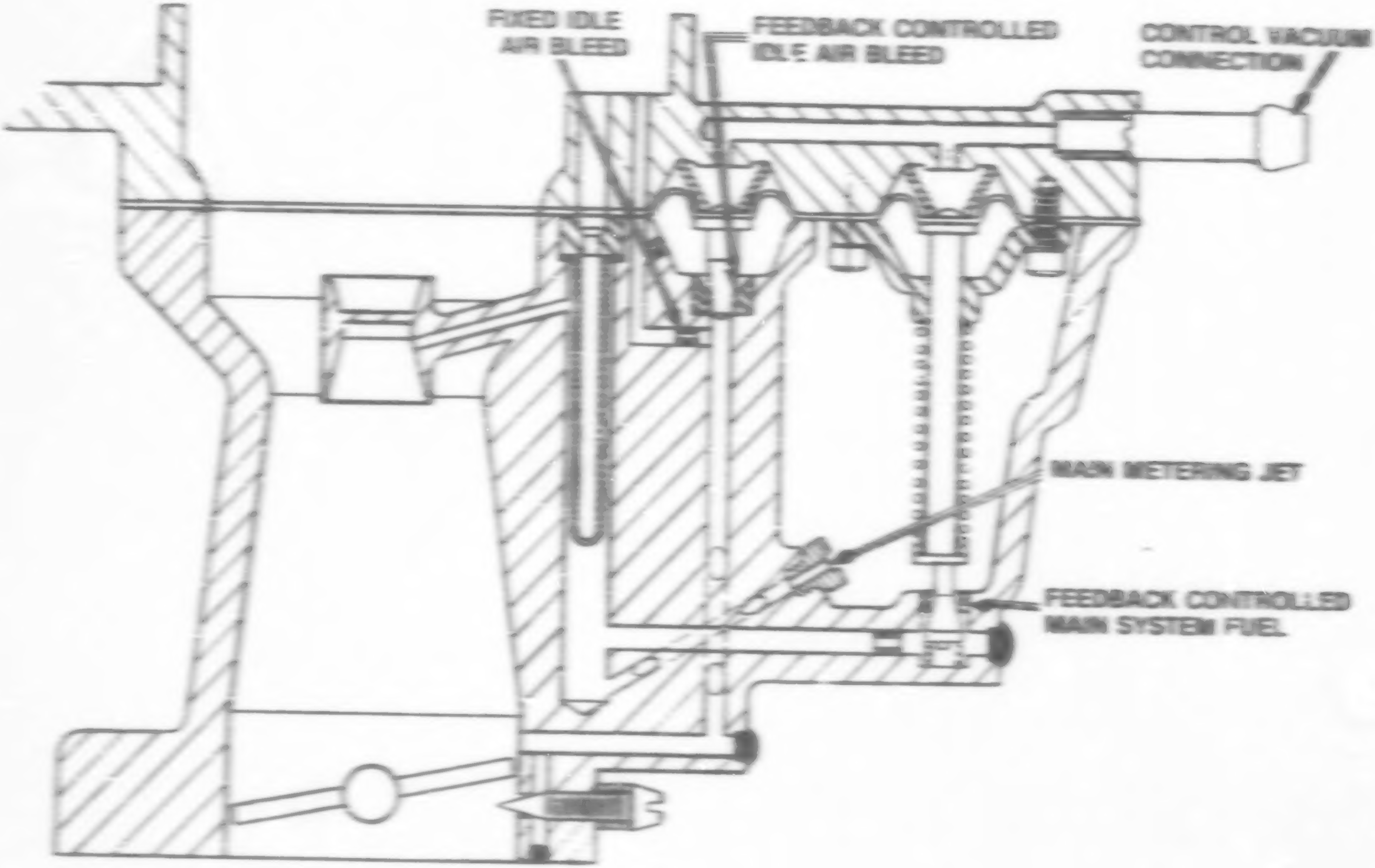
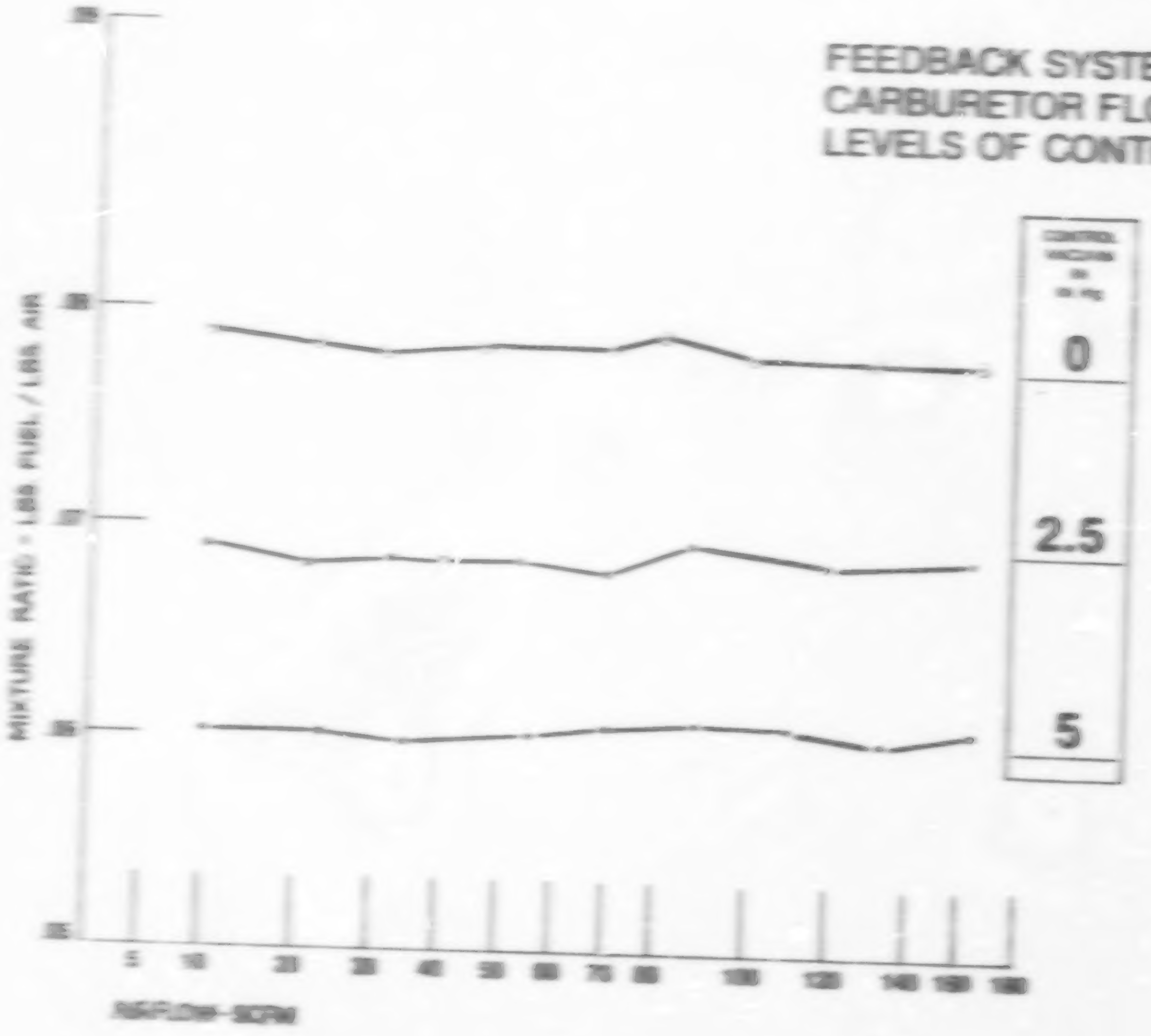

FIXED IDLE AIR BLEED
FEEDBACK CONTROLLED IDLE AIR BLEED
CONTROL VACUUM CONNECTION
MAIN METERING JET
FEEDBACK CONTROLLED MAIN SYSTEM FUEL

Figure Holley-3

HOLLEY FEEDBACK CARBURETOR PERFORMANCE



FEEDBACK SYSTEM CONTROL OF CARBURETOR FLOW AT VARIOUS LEVELS OF CONTROL VACUUM

Vehicle tests were reported on a modified 1976 Pinto at 2750 pounds IW with the 2.3 litre engine, an automatic transmission, and a 3.18 rear axle. Emission control equipment included the Holley feedback carburetion system, backpressure EGR, AIR, and a 3-way plus oxidation catalyst system. The vehicle had accumulated less than 3000 miles. These low mileage test results are shown in Table Holley-1.

Table Holley-1*

Low Mileage Testing of 2.3 litre Pinto

	HC	CO	NOx	MPG_U
	0.152	3.29	0.436	20.48
	0.165	2.79	0.434	21.37
	0.136	2.56	0.420	21.65
	0.165	3.22	0.502	21.42
Average	0.15	2.96	0.45	21.43

The similar fuel economy vehicle** from 1977 Federal certification achieved 23.0-23.4 MPG_U.

The driveability of the vehicle with feedback carburetion was said to be improved over the driveability of the vehicle in its original 1976 California configuration, except at idle. Apparently, engine surge was experienced with feedback idle operation. The elimination of lean stretchiness at part throttle was said to be the biggest improvement in driveability.

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*From Holley Status Report, December 1976, pages 3 and 4.

**VIN 7Y1-2.3-F-43.

Holley will provide only the carburetor and vacuum control valve to Ford. The carburetor will cost 5-10% more than the similar open loop carburetor which is being replaced and the vacuum control valve will cost less than $5.00, according to Holley.

Lead time requirements for the modification of an existing carburetor to feedback control ranges from 18 to 30 months, depending on the necessary design changes and availability of prototype tooling. Holley also indicated that they would need two model years to introduce feedback modifications for all their production carburetors.

The developmental efforts of Holley have made production feasible, feedback carburetion available to many vehicle manufacturers for the first time. Consequently, data which can be used to directly compare feedback carburetion to feedback fuel injection may now become available.

Perhaps the biggest problem for the Holley system is the apparent lack of demonstrated durability. It appears that if the feedback carburetors are durable and can provide reasonable emissions and fuel economy when compared to fuel injection, the domestic vehicle manufacturers will probably continue to use carburetion because of the cost differential between carburetion and injection. Thus the slower system time response which is associated with intake manifold wall wetting will probably continue to be accepted by the industry.

7.2.7. Matthey Bishop Inc. (MB)

Matthey Bishop Inc. is the U.S. subsidiary of Johnson Matthey Chemicals, Ltd. Their major activity in the automotive emission control area is the development and manufacture of catalysts. They have tended to specialize in monolithic substrate catalysts and their major customer has been the Ford Motor Company.

MB responded to EPA's request for information with some interesting reports on progress in the areas of oxidation catalysts and 3-way catalysts.

Along with the other catalyst manufacturers, MB has been striving to reduce the amounts of noble metal and washcoat in their catalysts. Significant reductions in these items have already been made on production catalysts since the large scale introduction of catalysts in 1975. For example, a representative monolithic substrate noble metal loading for 1977 model year catalysts is approximately 25 gm/cu ft., whereas in 1975 the loading was in the area of 40 gm/cu ft. MB is striving to reduce the loading still further and initial results indicate that from a low mileage activity point of view this may be possible. However, their testing has shown that maintaining high catalyst efficiency at high mileage may be the limiting factor.

Two types of laboratory aging testing have been performed. The first type was poisoning with fuel containing 0.024 gm/gallon of lead. This poisoning resulted in some reduction in activity as shown in Table MB-1.

Table MB-1

Effect of Catalyst Aging on a Cycle Emphasizing Poisoning

	Loadings		Steady State Conversion Eff.					
	Washcoat	Noble Metal	35 hrs		127 hrs		293 hrs	
System	gm/cu in.	gm/cu ft.	HC	CO	HC	CO	HC	CO
Standard	1.75	25	94	100	92	100	84	100
Low NM	1.75	15	91	100	48	100	78	100
Low WC	1.2	25	89	100	67	100	80	100
Low WC	0.8	25	89	100	88	100	80	100

MB also presented data showing the effect of high temperature on the durability of catalysts like those in Table MB-1. The aging cycle presented the catalysts with an 800°C (1472°F) inlet exhaust gas temperature for half of the time. The results are shown in Table MB-2. These results indicate that low noble metal and low washcoat formulation do not hold up nearly as well under high temperature operation.

Table MB-2

Effect of Catalyst Aging on a Cycle Emphasizing Thermal Degradation

	Loadings		Steady State Conversion Eff.							
	Washcoat	Noble Metal	50hrs		100 hrs		200 hrs		300 hrs	
System	gm/cu in.	gm/cu ft.	HC	CO	HC	CO	HC	CO	HC	CO
Standard	1.75	25	78	99	76	96	66	94	60	92
Low NM	1.75	15	72	97	69	94	57	93	51	88
Low WC	1.2	25	75	96	69	93	58	90	52	79
Low WC	0.8	25	68	95	63	93	46	63	30	21

MB presented some very interesting and potentially significant information on metal substrate catalysts. Current monolithic catalysts use ceramic substrates. Metal substrates offer the promise of improved shock and vibration resistance along with reduced size. This last advantage may be the most important. This is because on some installations requiring a "close coupling" of the catalyst to the exhaust manifold, a limiting condition may be available space. Close coupling is advantageous because the exhaust gas is at a higher temperature when it arrives at the catalyst. This has advantages in the areas of quicker light-off and improved conversion efficiency. Close coupling is particularly important for start catalysts and 3-way catalysts. MB claims that by using a metal substrate, the cell wall thickness can be reduced to as low as 2 mil (0.002 in.). This allows a metal substrate catalyst of 400 cells per square inch (CPSI) to be fabricated and coated with ease of a 300 CPSI ceramic monolith. MB indicated that their calculations show that a metal substrate catalyst need only be half the volume of a ceramic substrate catalyst to give equivalent performance, assuming the same noble metal content for both. Conversely, a conventional catalyst could be replaced by a metal substrate catalyst of the same volume to yield improved catalyst efficiencies. Table MB-3 compares the performance of a 34 cu in. metal substrate with a 75 cu in. ceramic substrate, using an aging cycle which included severe mechanical and thermal shock.

Table MB-3

Metal Substrate vs. Ceramic Substrate

Catalyst Type	Hours Aged	Conversion % Eff. HC	 CO
34 cu in.	0	81	91
400 CPSI, Metal	100	61	87
Pt/Pd ratio 2:1 56 gm/cu ft.	200	68	88
	300	64	86
75 cu in.	0	84	93
300 CPSI, Ceramic	100	69	90
Pt/Pd ratio 2:1 25 gm/cu ft.	200	69	86
	300	64	89

MB reported progress in 3-way catalyst development. They indicate that their development approach has emphasized the importance of air-fuel ratio perturbations of controlled amplitude and frequency. All of MB's reported work on 3-way catalysts involved formulations containing an 11:1 Pt/Rh ratio and a 46 gm/cu ft. noble metal loading. Table MB-4 contains CVS test results (assumed to be 1975 FTP) for two of their formulations. Table MB-5 contains steady state conversion efficiency data for some later formulations. These later formulations appear to perform quite well.

Table MB-4

3-Way Catalyst Test Results (VW Beetle with Bosch L-Jetronic EFI) on Full-Sized Catalysts (at 11:1) Aged by a 3-Way Catalyst Cycle

Catalyst	Pollutant	0 Hour Emissions (gm/mi)(75 FTP) Baseline	Sum Wt.	% Conv.	265 Hour Emissions (gm/mi)(75 FTP) Baseline	Sum Wt.	% Conv.
TWC-1	NOx	2.82	0.77	77	2.82	0.92	67
TWC-2	NOx	2.82	0.69	76	2.79	0.93	67
TWC-1	HC	1.05	0.33	69	0.86	0.22	74
TWC-2	HC	1.05	0.21	80	0.94	0.21	78
TWC-1	CO	12.9	2.88	78	12.0	2.85	76
TWC-2	CO	12.9	1.92	85	12.6	2.56	80

Table HB-5

Steady State Efficiencies HB 3-Way Catalysts after 300 Hours Dyno Aging by 3-Way Catalyst Cycle

Perturbation = 1 A/F at 1 Hz

A/F = 14.6

Catalyst	Gross NOx	HC	CO
TWC-3	62	94	93
TWC-4	75	94	93
TWC-5	77	95	97
TWC-6	80	93	97

A/F = 14.5

Catalyst	Gross NOx	HC	CO
TWC-3	68	94	84
TWC-4	85	94	87
TWC-5	93	95	92
TWC-6	87	93	92

MB reported some interesting data on the sulfuric acid emission characteristics of platinum/rhodium catalysts. Their test data show a dramatic drop off in sulfuric acid emission following a cool down period. The catalyst had been run continuously for 500 hours, with periodic sulfuric acid emission testing, prior to this cool down. After the cool down the sulfuric acid emission level dropped to one fourth its former level. MB indicates that this may result from a catalyst surface enrichment in rhodium that occurs during the cool down.

MB reported data on the effect of noble metal content and air-fuel ratio on HCN emissions. Note that data show the net increase in HCN over the catalyst. Table MB-6 shows this data.

Table MB-6

Net HCN Production by Various Matthey Bishop Catalysts at 500°C
50,000 hr^{-1} SV, as a Function of A/F Ratio (Stoich. = 14.7)

	*HCN Produced, ppm, at A/F ratio of				
System**	14.0	14.3	14.5	14.7	14.9
100 % Pt	1.5	1.0	1.0	1.0	1.0
33 % Pd	2.0	1.0	1.5	1.5	1.0
2.5 % Rh	3.0	1.5	1.5	1.5	1.0
7.5 % Rh	32	17	2.0	1.5	-
15 % Rh	9	4	1.0	0.5	0.5

* Inlet HCN (baseline): 5 ppm

** Major component of all systems is platinum

MB is in active competition with the other leading catalyst manufacturers in the development of 3-way catalysts. They are presently concentrating on an 11:1 platinum/rhodium ratio which appears to show fairly good results.

7.2.8. Questor

7.2.8.1. Systems Under Development

Questor's Reverter System entails a three-step process involving limited thermal oxidation of CO, HC, and H_2; catalytic reduction of NOx; and then further oxidation of remaining CO, HC, and H_2. The system can be thought of as a rich thermal reactor, followed by a NOx catalyst, followed by a lean thermal reactor. This is basically the same system as the one reported in last year's status report.

The system operates moderately rich (13.0:1 to about 14.2:1 A/F ratio) using limited port air injection via an air pump for nominal O_2/CO ranges of 0.05 to 0.4, a rich thermal reactor where exhaust gas temperatures range from 1550-1750°F, a base metal catalyst with a combination of Cu, Cr, and Ni powder sintered to a base metal substrate, and finally, secondary air injection into another lean thermal reactor section in an amount roughly equal to that injected at the ports. These three steps correspond to areas A, B, and C, respectively, in Figure Questor-1.

A Reverter system is being installed at Chrysler on a 318 CID equipped B-body vehicle incorporating open loop, electronic fuel injection (EFI). An identical system will be installed on a 318 CID Cordoba with EFI owned by Houston Chemical. Houston Chemical is a manufacturer of lead additives for gasoline. They have an interest in lead-tolerant emission control systems, and the Questor system appears to be one. Test results from these systems will be compared to results using engines equipped with conventional carburetors. Previous work shows deviations in CO results partly due to carburetor air-fuel ratio drift.

The Houston Chemical vehicle is intended for use in continuing their lead tolerance testing. Previous testing involved use of a Reverter

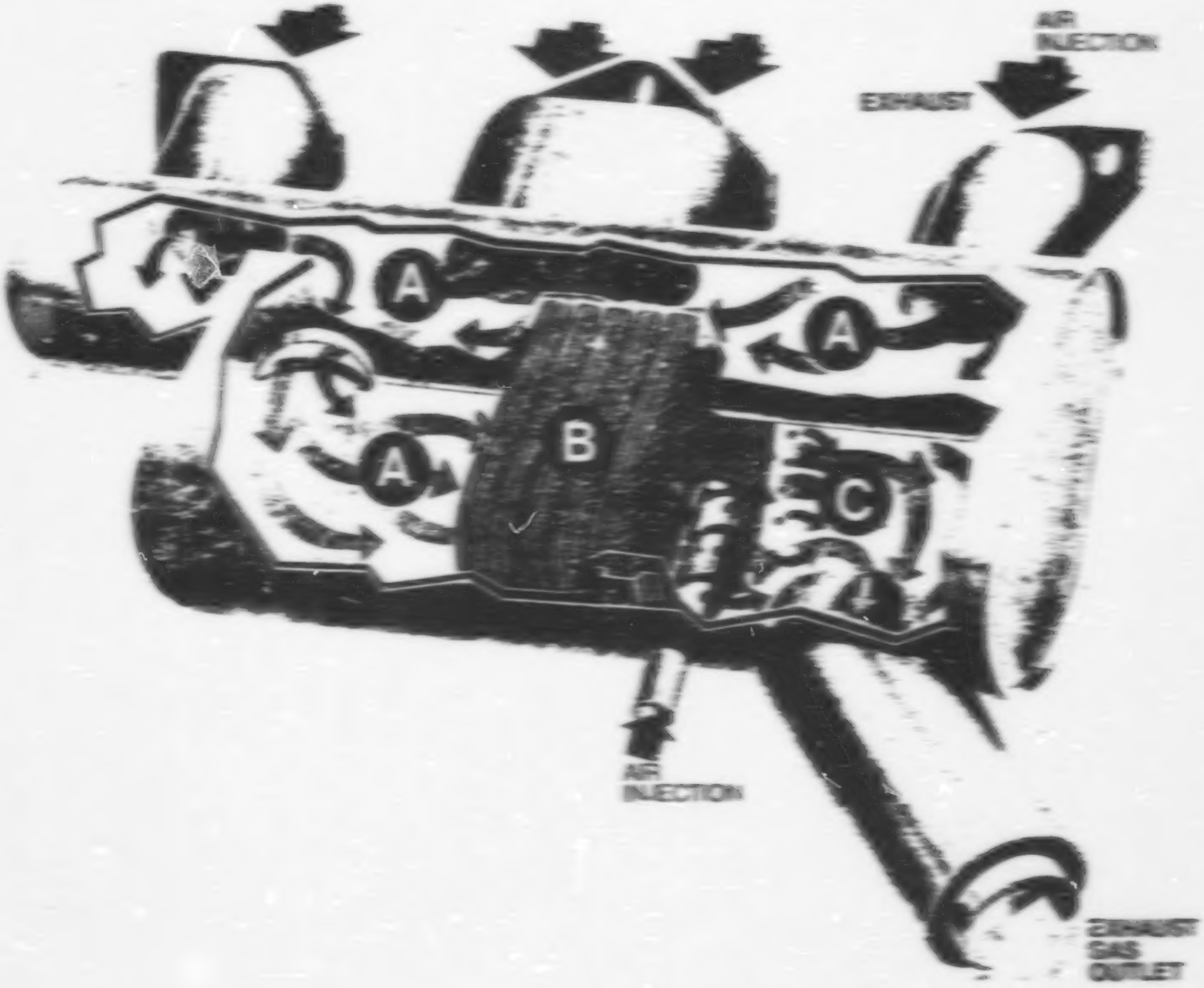
AIR INJECTION
EXHAUST
A
A
A
B
C
AIR INJECTION
EXHAUST GAS OUTLET

Figure Questor-1

Questor's Reverter System

equipped Pinto. Though somewhat limited testing was performed, hot start tests showed that as lead content increased, HC, CO, and NOx emissions increased with little or no effect on fuel economy. These tests were performed on the same day using the same driver and analytical equipment. Averaged emission results are presented in Table Questor-1. Exhaust gas temperatures taken in the first reactor, 1/4 in. ahead of the NOx catalyst, showed decreasing exhaust temperatures (as much as 200°F, 3 minutes into hot start) with increased fuel lead content. Questor indicated that additional use of lead retards the reaction rates of the partial oxidation zone disturbing the operating status of not only the partial oxidation zone (step 1), but also catalytic reduction and final oxidation (steps 2 and 3, respectively).

Table Questor-1

Lead Tolerance Test Results of the Questor Reverter System

1974 Pinto Wagon, 2.3 litre, 3000 lb IW
CVS hot start bags 2 & 3, 11.3 hp setting

	----avg gm/mi----			
Pb, gm/gal (nominal)	HC	CO	NOx	MPG
~ 0	0.058	2.678	0.205	17.1
0.5	0.073	2.975	0.351	16.8
1.5	0.115	4.468	0.344	16.9
3.0	0.190	6.115	0.414	17.3

7.2.8.2. Systems to be Used at Various Emission Levels

0.41 HC, 3.4 CO, 0.4 NOx

The Questor Reverter System was developed to meet statutory emission levels. Emissions performance to date have been generally promising.

however, CO control shows some inconsistency. This may be due to the inability of the carburetor to hold the desired air-fuel ratio. Some emission results are presented in Table Questor-2 and Table Questor-3. The loss of CO control at zero mileage and the fluctuating level of NOx at 5000 miles in Table Quertor-3 could not be explained by Questor.

Table Questor-2

Emission Results with Questor's Third Generation Reverter

Vehicle	Date	Lab	Fuel	HC	CO	NOx	MPG_u	MPG_h
				gm/mi				
1974 Pinto	11/24/75	AP	Indolene	0.03	2.32	0.26	16.2	-
2.3 litre	11/26/75	AP	Clear	0.08	2.50	0.25	16.0	-
2V Carb	12/01/75	AP		0.04	1.85	0.24	16.0	-
Veh. #HC-53	12/04/75	GM		0.08	4.90	0.26	14.9	18.7
	12/05/75	GM		0.05	3.90	0.25	15.6	19.2
	12/08/75	GM		0.05	4.00	0.14	16.0	-
	12/09/75	GM		0.06	3.70	0.15	16.2	-
	12/15/75	GM		0.06	5.70	0.21	14.5	-
	12/17/75	GM		0.05	2.80	0.28	15.8	19.5
	12/18/75	GM		0.04	2.70	0.22	15.8	-
	1/12/76	GM		0.05	4.70	0.19	15.9	20.0
		Average		0.05	3.55	0.22	15.7	19.4
	12/19/75	GM	Indolene	0.07	3.9	0.34	15.8	19.7
	1/08/76	GM	30	0.10	6.6	0.25	15.5	19.3
		Average		0.08	5.2	0.30	15.6	19.5

Table Questor-3

Emission Results with Questor's Third Generation Reverter

Vehicle	Date	Mileage	Lab	Fuel	gm/mi HC	gm/mi CO	gm/mi NOx	MPG_U
1973 Pinto	1/14/76	Zero	AP	Indolene	0.13	3.21	0.25	16.5
2.3 litre	1/15/76		AP	Clear	0.12	2.98	-	16.7
2-V Carb	1/16/76		AP		0.08	2.80	0.27	17.0
	2/27/76		Ford		0.09	2.93	0.23	15.6
	3/01/76		Ford		0.08	2.39	0.25	15.1
	3/02/76		Ford		0.09	4.34	0.18	15.8
	3/02/76		Ford		0.13	3.88	0.38	16.2
	3/03/76		Ford		0.08	5.24	0.16	16.0
			Average		0.10	3.47	0.25	16.1
	7/13/75	5000	Ford	Indolene	0.07	3.08	0.42	16.7
	7/14/75		Ford	Clear	0.07	3.10	1.05	16.7
	7/15/75		Ford		0.09	4.58	0.27	16.2
	7/15/75		Ford		0.07	2.68	0.68	16.4
			Average		0.08	3.36	0.60	16.5

Inspections of the Reverter hardware and its air management controls showed no apparent malfunctions. Testing is to continue to the 10,000 mile interval where NOx control will again be examined. Fuel economy continues to be a problem with the Reverter system primarily due to the richer than stoichiometric air-fuel ratios used. Typical 1977 Pinto certification results show average urban fuel economy of about 21.5 MPG_U compared with the Questor Pinto which is averaging about 16.3 MPG_U.

7.2.8.3. Durability Testing

Other than the data reported in Table Questor-3, no durability data were presented. The Chrysler B-body test vehicle described above is being equipped with a Reverter system and is designated to undergo durability testing. To help increase system durability, the geometry of this system was kept as simple as engine space constraints would allow to reduce the magnitude of residual stresses created through complex forming operations. Electron beam welding is also used to help alleviate residual stresses. Installation and initial testing were expected to be completed in January 1977, thus no test data were reported.

7.2.8.4. Problems and Progress

As mentioned above the fuel economy of vehicles equipped with Reverter systems continues to be a problem. This may be primarily due to the rich carburetor settings used in this system. CO results have been somewhat inconsistent possibly due to carburetor air-fuel ratio drift. Results from EFI equipped vehicles will be compared with previous results for possible improvements in both fuel economy and emissions over carbureted vehicles.

A total development program of the Reverter system cannot be pursued by Questor for financial reasons. As interest is generated in the automotive manufacturers and others, financial backing from these parties can be used for further development.

7.2.9. Universal Oil Products, Inc. (UOP)

7.2.9.1. Systems Under Development

Oxidation Catalysts

Though no data were presented, UOP has done work on developing a monolithic start catalyst. These are presently available on a commercial basis. No further effort was reported by UOP.

3-Way Catalysts

Three-way catalyst development was the largest area of effort reported. UOP has been directing their 3-way catalyst development programs with an objective of reaching a platinum/rhodium ratio of 20-30:1 and a total noble metal loading of 25-40 gm/cu ft.

The noble metal loadings in catalysts (4" dia x 6" long monolithic substrates having 300 cells/sq in.) which have been prepared and evaluated by UOP are described in Table UOP-1. Catalyst #PZM-360911 is roughly within the above objectives of UOP.

Table UOP-1

Noble Metal Loadings in UOP Catalysts

	Noble Metal Loadings (gm/piece)				
Catalyst	Pt	Rh	Pt/Rh Ratio	gm total loading	gm/cu ft.
PZM-35106	1.89	0.31	6:1	2.20	50.42
PZM-36039	2.50	0.25	10:1	2.75	63.03
PZM-36089	1.60	0.16	10:1	1.76	40.34
PZM-360911	1.14	0.06	19:1	1.20	27.50

A steady state dynamometer procedure is used to evaluate these catalysts. Table UOP-2 shows aging data using catalyst #PZM-360911. UOP indicates that zero mile conversion efficiencies should be between 80-90% for HC, CO, and NOx over the '75 FTP with this catalyst. The durability of low rhodium catalysts is presently unknown to UOP. Programs to obtain this information using actual vehicle testing are expected to be concluded within the next six months. No data were reported for the other catalysts listed in Table UOP-1.

Table UOP-2

Steady-State Dynamometer Evaluation of Catalyst #PZM-360911

Test Hours	NO/CO Intercept %	NO/HC Intercept %	Maximum Efficiencies % HC	CO	NOx	NOx % Efficiency Under Rich Conditions (2% CO)
6	74.5	85.7	86	83	97	90
60	77.9	80.7	83	84	94	73
120	75.5	82.5	84	85	91	47
180	71.8	80.8	83	82	88	26
240	72.7	76.3	79	84	88	13

UOP is also involved in the preparation and evaluation of pelleted 3-way catalysts. Though no data were reported, additional work is presently being directed toward increasing the Pt/Rh ratio (from the 9:1 ratio which UOP reports is available commercially at present), and improving HC and NOx activity and durability.

Some testing of catalysts having Pt/Rh ratios of from 4:1 to 18:1 has been performed to study the effect of Pt/Rh ratio on the production of sulfuric acid emissions. No data were reported.

Other Development Efforts

Another program to study the production of HCN under rich conditions using a laboratory test procedure has been established by UOP. No results are available.

7.2.9.2. Systems to be Used at Various Emission Levels

No specific system to be used to meet any particular emission level was identified by UOP.

7.2.9.3. Durability Testing

No data were reported.

7.2.9.4. Progress and Problems

The supply of rhodium was discussed briefly by UOP. They reported that recent information (Metals Week, 31 January 1977, page 2) indicates that South African platinum mines would be able to supply 33,000 troy ounces of rhodium per year to the U. S. automobile industry. This figure is 5.5% of the platinum supplied to automakers, and would require a ratio of platinum to rhodium of about 18:1 if 3-way catalysts were to be employed on all vehicles. Assuming a figure of ten million vehicles/model year, the allowed rhodium loading per vehicle would be 0.1 gm if all vehicles were equipped with 3-way catalysts. An alternative situation would involve half the vehicles (5×10^6 vehicles) being equipped with oxidation catalysts and the remainder being equipped with 3-way catalysts. This situation would theoretically permit the use of 0.2 gm of rhodium per vehicle for those equipped with 3-way catalysts. The platinum to rhodium ratio could also be reduced to about 10:1 under these conditions if this were necessary.

UOP's objectives to reduce total catalyst loadings and increase Pt/Rh ratios are admirable, but UOP did not report any vehicle test results to EPA that would indicate how UOP's catalysts compare with those of other catalyst manufacturers.

7.2.10. Walker Manufacturing

Submissions for this year's status report were requested from the Manufacturers of Emission Controls Association (MECA) of which Walker Manufacturing is a member. Walker furnished parts for the GM oxidation catalyst and is assembling the Ford oxidation catalyst in their Ohio plant. Research and development is carried in Walker's Grass Lake, Michigan Engineering and Research Laboratories.

Walker submitted a response to the MECA request which outlined their test results of selected monolithic catalysts in comparison to production pelleted catalysts. After evaluations using an engine dynamometer, Walker decided to use a Matthey-Bishop 3C oxidation catalyst for their vehicle comparison testing. These monolithic catalysts were on a W. R. Grace substrate with a cell density of 306 cells per square inch, a Pt/Rh 40 gm/cu ft. loading level, 0.0854 troy ounces of precious metal, and an effective volume of 96 cubic inches. The vehicles selected for durability testing were three 454 CID equipped, full sized Chevrolets (EVT-1,2,3) and a 140 CID Vega (EVT-6). The Vega and two of the Chevrolets were driven 30,000 non-AMA durability miles and the other Chevrolet was driven 30,000 miles. Emission tests were performed every 5,000 miles and before and after any significant maintenance. These emission results can be found in Table Walker-1. Sulfate or hydrogen cyanide emissions were evaluated nor any high altitude or non-FTP temperatures and speeds evaluated. Additional tests are scheduled for these vehicles.

Walker placed the following constraints on the catalyst selection: (1) the converter must be packaged within the location of the original equipment converter, (2) production substrates and catalysts must be used, and (3) the vehicle emission control system would remain unchanged. Operating within these constraints, Walker attempted to determine how long and to what levels tailpipe emissions could be controlled, and

Table Walker-1

TABULATED CVS RESULTS*

[illegible]

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*From Walker Manufacturing Status Report submission, page Figure 9.

Walker Manufacturing Co.
12/15/76

to determine how inlet emission levels (engine-out) affect the choice of catalyst volume. Consequently, Walker made the following tentative conclusions based on the data accumulated by Walker to date:

1. The minimum catalyst volume required to meet any emission standard is dependent on feedgas composition (See Figure Walker-1).

2. The volume of catalyst required to just meet a tailpipe emission standard on an individual vehicle may be quite small. Feedgas concentration tolerance spread requires relatively large catalyst volumes to ensure all vehicles of a particular production group meeting standards.

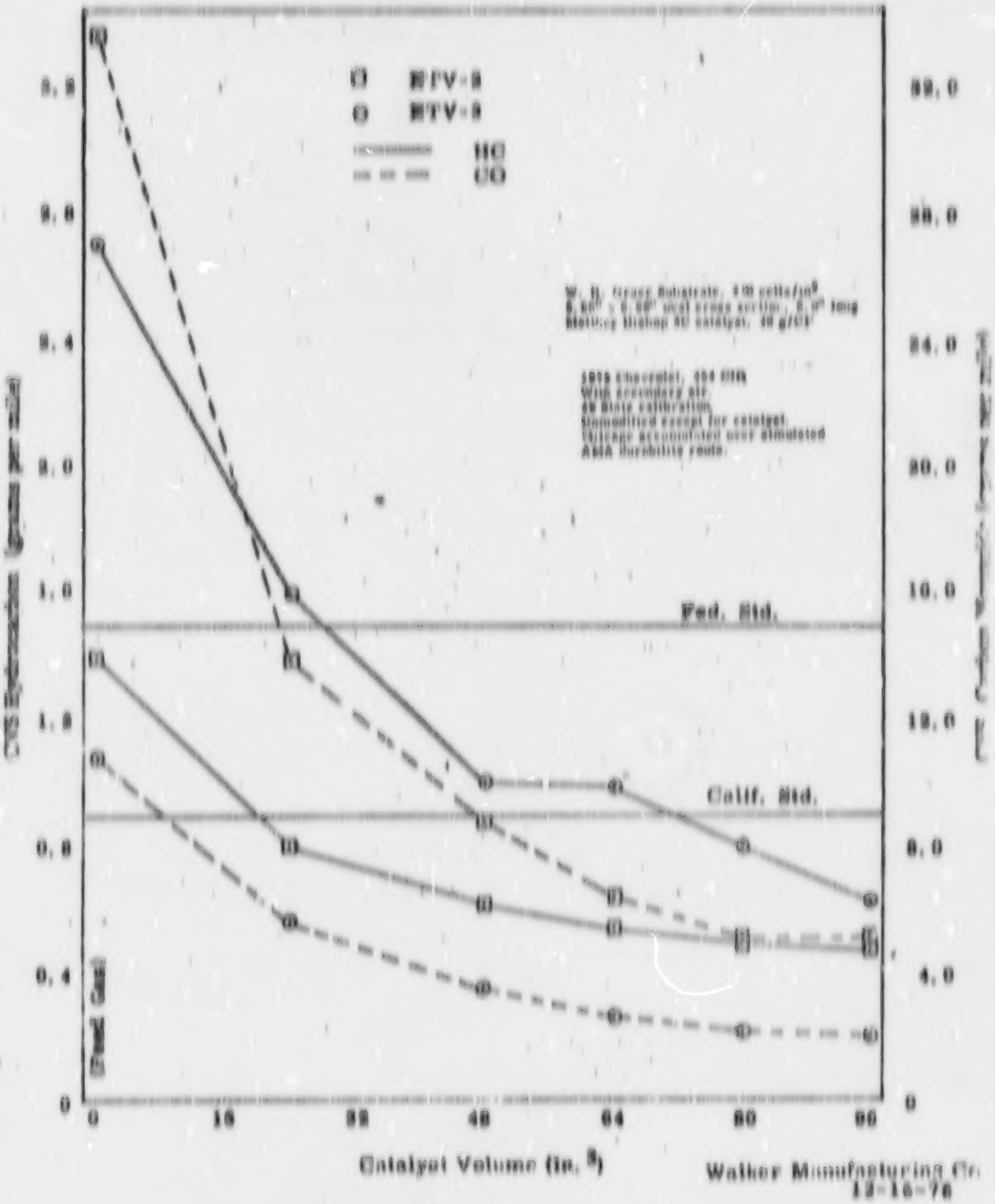
3. Figures Walker-1 and Walker-2 imply that, at a given feedgas concentration level, increasing catalyst volume beyond the knee in the curves is an inefficient and costly method to further reduce tailpipe emissions.

4. Figures Walker-1 and Walker-2 together show that feedgas concentration level reductions have a much more pronounced effect on tailpipe emission reductions than do large catalyst volume increases.

5. Figures Walker-3 and Walker-4 indicate that specific activity variations exist on typical catalyst-substrate combinations in the fresh state. Presumably this is true in the aged state also, although this has not been determined. It is noteworthy in any case, that large volume increases are necessary (greater than 2 times) to attain the final 10 to 15% increase in conversion efficiency.

Figure Walker-1

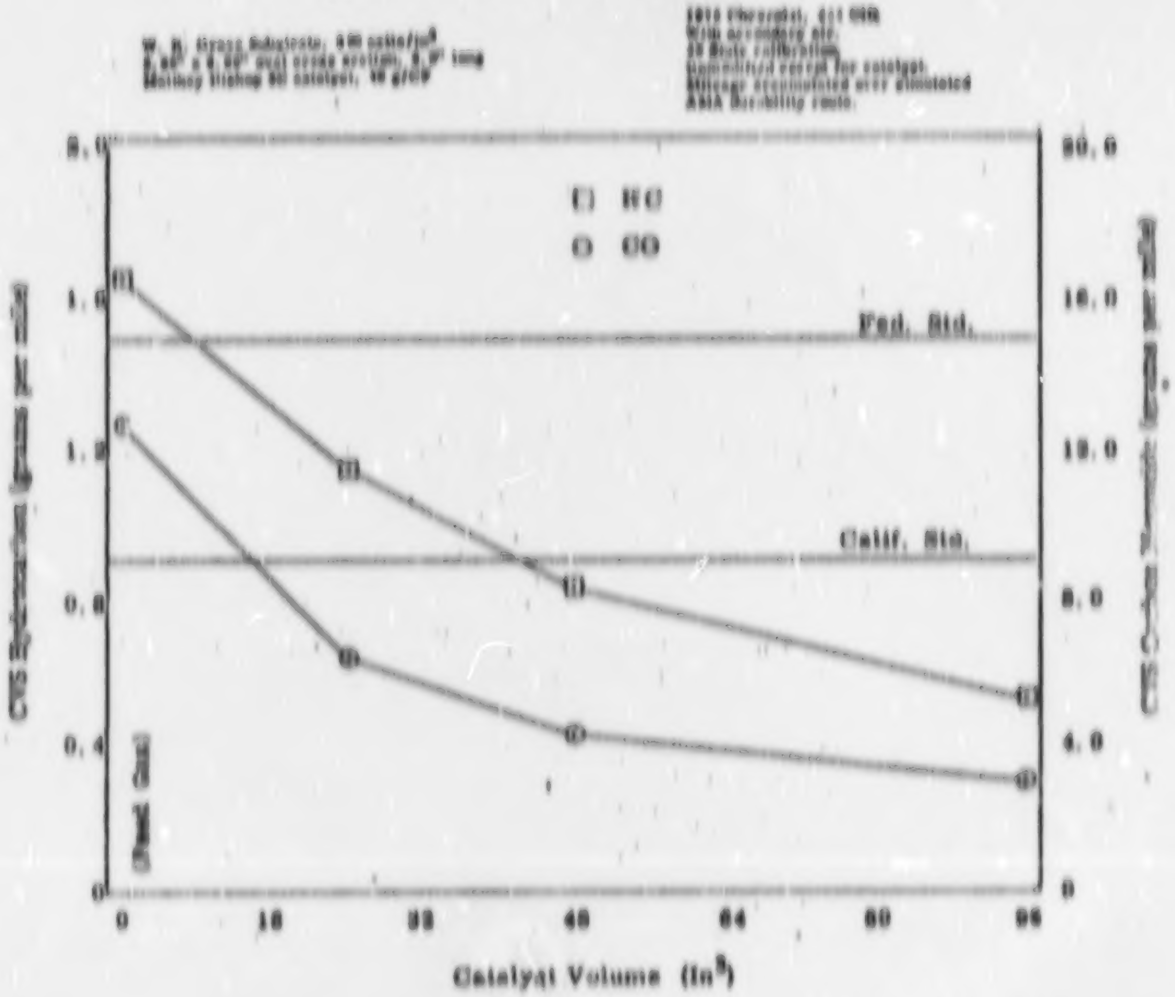
CVS Test Results as a Function of Catalyst Volume (AM-34 at 50,000 miles) For Two 454 CID Chevrolets



Walker Manufacturing Co.
12-15-76

Figure Walker-2

CVS Test Results as a Function of Catalyst Volume for the ETV-1/AM-33 System (AM-33 at 50,000 Miles)



Walker Manufacturing Co.
12-16-76

Comparison of Carbon Monoxide Hot Conversion Efficiency versus Substrate Volume for Four Fresh Catalyst/Substrate Systems

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Dynamometer tests at 120 SCFM Carburetor Air Flow

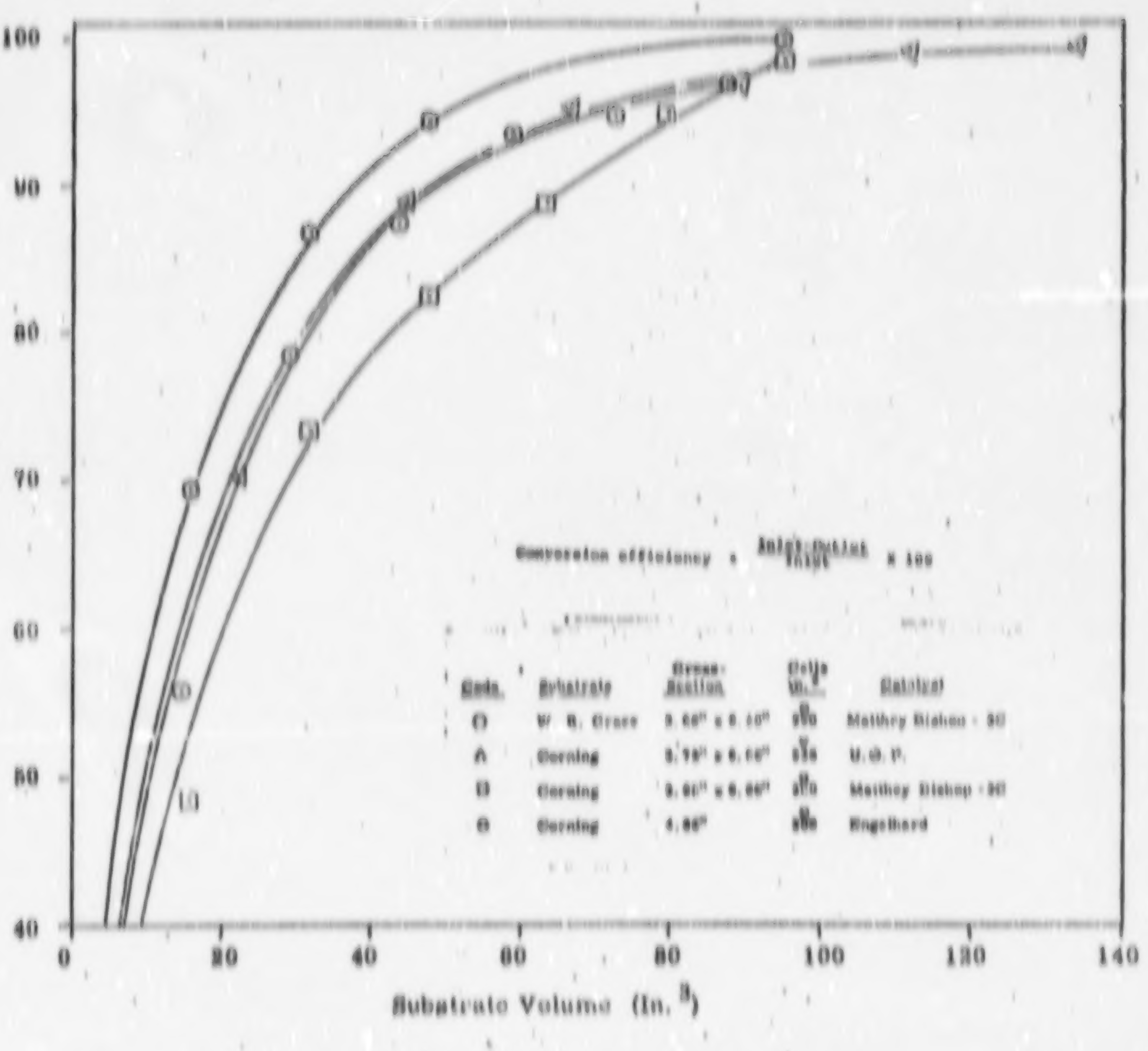

Figure Walker-3

Walker Manufacturing Co.
E.S. 12-15-76

6. An effective catalyst system to meet the statutory emission levels of 0.41 HC, 3.4 CO requires reductions in feedgas concentrations and in feedgas variation between identical vehicles.

As indicated above, the six statements are conclusions made by Walker.

An interesting result of the Walker study lies not in the effects of a monolithic oxidation catalyst versus a pelleted catalyst, but in their conclusion that closer control of engine out emissions has a more beneficial effect than increasing oxidation catalyst volume. Therefore, if techniques were applied to reduce engine-out emission variability, like using improved fuel metering and air injection systems, then the emission reduction load on the catalyst can be reduced with subsequent lowering of precious metal loading or catalyst volume. The conclusion that large catalyst volumes are inefficient and costly may be in error as a 10-15% improvement in efficiency is not small. The cost and efficiency of the utilization of larger catalyst volumes must be compared to both the incremental degree of emission control required to achieve a given emission goal, and the cost of alternate solutions to the accomplishment of the emissions goal before such a conclusion can be drawn.

The Walker results should also be interpreted in light of the basic constraints placed on the program. It is not apparent that retrofitting GM's pellets with monoliths using the same car with no changes in the vehicle's emission control system is what would actually be done to achieve lower emissions.

One of the more important conclusions to be drawn from the Walker results is that larger catalyst volumes reduce emissions. A bigger monolithic catalyst is better, in other words. The largest catalyst volume to engine displacement ratio reported by Walker was 0.21 (96/454), and in general the curves indicated that even larger catalysts would have had even lower emissions. This indicates that higher catalyst volume to engine displacement values may be needed in the future to achieve low emission levels, and some manufacturers are examining catalyst volume to engine displacement ratios closer to 1.0, compared to the 0.21 ratio examined by Walker.

7.3. Foreign Manufacturers

7.3.1. Bayerische Motoren Werke (BMW)

7.3.1.1. Systems Under Development

After an absence of a year, BMW submitted a report concerning the systems they have under development to meet the various proposed exhaust emission standards. Unfortunately, most of the systems that BMW has under development were included in a confidential cost section which precludes discussion of these developments in this report. However, BMW did mention that they were working on a 3-way catalyst system for levels of 0.41 HC, 3.4 CO, 1.0 NOx and lower. At levels higher than these, BMW will continue to update their 1977 systems with the exception of the 320i model vehicles which will use an oxidation catalyst, secondary air injection and EGR for 1979.

3-Way Catalyst System

BMW briefly discussed their progress in developing a 3-way system for their vehicles. BMW is optimizing the time delay of the closed loop 3-way system to improve both HC and CO emissions and driveability. To date, BMW reported results of 0.255 HC, 4.338 CO and 0.267 NOx with a 20 millisecond (ms) time delay and 0.257 HC, 3.486 CO, and 0.382 NOx with a 10 ms time delay. Additional work is being carried out to optimize warm-up and driveability. All the previous work was conducted using an Engelhard TWC-14 catalyst. BMW is also determining O_2 sensor location for optimum sensor life, warm-up, and system control. The BMW 3-way catalyst system schematic is shown in Figure BMW-1.

The only development emission data BMW supplied for the 3-way catalyst on the 3 litre-530 model vehicle were average FTP results of 0.6 HC, 5.0 CO, and 0.4 NOx with fuel economies of 14.4 MPG_u and 22.5 MPG_h. BMW stated more work is necessary on the selection of catalyst volume to

ENGINEERING EMISSION CONTROL

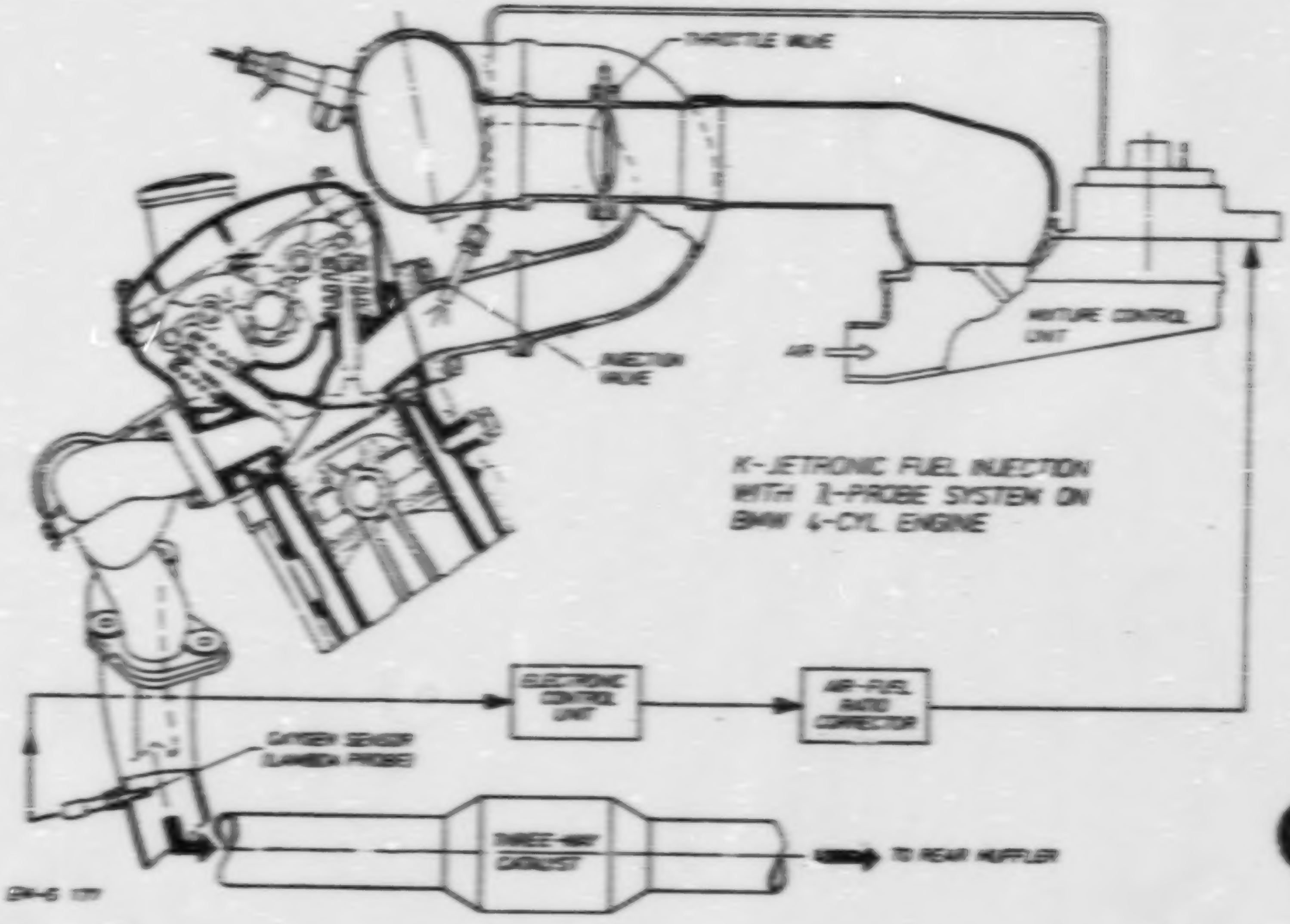
THROTTLE VALVE
INJECTION VALVE
AIR
MIXTURE CONTROL UNIT
K-JETRONIC FUEL INJECTION
WITH λ-PROBE SYSTEM ON
BMW 4-CYL. ENGINE
ELECTRONIC CONTROL UNIT
AIR-FUEL RATIO CORRECTOR
OXYGEN SENSOR (LAMBDA PROBE)
THREE-WAY CATALYST
TO REAR MUFFLER
BM-G 177

Figure BMW-1

lower HC and CO levels. Work is to start in January 1977 to complete this optimization. BMW did supply data developed on the Japanese 10 and 11 mode test cycles for their 1977 model year vehicles.

7.3.1.2. Systems to be Used at Various Emission Levels

The systems BMW presently offers for model year 1977 and the corresponding emission levels and fuel economies can be found in Table BMW-1. BMW plans to have the following systems available for 1978 model year vehicles at emission levels of 1.5 HC, 15.0 CO, and 2.0 NOx.

Family	CID	Systems	Model	Sales
120.8	121.3	FI,EGR,TR,AP	320i, iA	Cal.
120.9	121.3	FI,EGR,AP	320i, iA	49 states
130.8	182.0	EFI,EGR,TR,AP	530i, iA	50 states
133.8	196.0	EFI,EGR,TR,AP	733i, iA	50 states
			633i, iA	50 states

FI = K-Jetronic Fuel Injection
EFI = L-Jetronic fuel injection
A = Automatic Transmission
EGR = Exhaust Gas Recirculation
TR = Thermal Reactor
AP = Air Pump

As previously stated, BMW plans to use a three-way catalyst system for all vehicles at emission levels lower than 0.41 HC, 3.4 CO, 1.0 NOx.

7.3.1.3. Durability Testing

BMW submitted no durability test data in this year's submission.

7.3.1.4. Progress and Problems

It is difficult to assess the extent of BMW's progress towards meeting emission levels lower than 0.9 HC, 9 CO, 2.0 NOx due to the paucity of data presented by BMW. Apparently BMW has not decided on the required volume for their 3-way catalyst system nor the precise control approach for their feedback control system.

Table BMW-1

BMW 1977 Model Year Durability and Data Vehicle Results

VIN	System	CID	Miles (10^3)	FTP Results (gm/mi)			Fuel Economy	
				HC	CO	NOx	MPG_u	MPG_h
662 BMW 121.0, 320i	AIR,FI,TR,EGR 2750 IW	121.3	5	0.35	6.6	1.30	18.6	-
			50	0.36	5.9	1.42	18.6	-
			Range	0.25-.37	5.3-8.0	1.13-1.42	17.2-19.5	
663 BMW 121.6 320i	AIR,FI,EGR 2750 IW	121.3	5	1.46	11.1	1.91	18.9	-
			50	0.97	8.5	1.57	18.7	-
			Range	0.90-1.46	8.2-13.7	1.57-1.91	17.8-19.5	
817 BMW 130.8 530i B	AIR,FI,TR,EGR 3000 IW	182.0	5	0.43	12.5	1.80	13.5	-
			50	0.27	8.1	1.60	14.6	-
			Range	0.27-.71	6.7-13.7	1.27-1.84	12.5-14.6	
5 480 001	AIR,EGR,FI,TR M4, Low Alt.	121.3	4	0.18	6.3	1.02	19.6	25.0
5 480 001	AIR,EGR,FI,TR M4, Hi Alt.	121.3	4	0.35	8.5	0.80	18.8	27.3
5 460 001	AIR,EGR,FI,TR A, Low Alt.	121.3	4	0.32	8.5	1.05	19.7	25.0
5 476 002	AIR,EGR,FI A, Low Alt.	121.3	4	1.00	8.5	1.31	18.7	24.8
5 420 004	AIR,EGR,FI M4, Low Alt.	121.3	4	1.13	8.6	1.40	26.2	29.5
6 375 045	AIR,EGR,FI,TR A, Low Alt.	182.0	4	0.28	4.7	1.06	13.1	18.1

Table BMW-1 (con't)

VIN	System	CID	Miles (10³)	FTP Results (gm/mi) HC	CO	NOx	Fuel Economy MPG_u	MPG_h
5 011 506	AIR,EGR,FI,TR MS, Low Alt.	182.0	4	0.36	7.2	1.04	13.5	20.1
4 375 046	AIR,EGR,FI,TR MS, Low Alt.	182.0	4	0.30	8.7	1.62	14.5	27.6
4 375 046	AIR,EGR,FI,TR MS, Hi Alt.	182.0	4	0.50	14.2	1.48	14.4	21.9
5 031 428	AIR,EGR,FI,TR A, Low Alt.	182.0	4	0.42	14.8	1.38	14.5	20.3

Evidently BMW will need to conduct accelerated testing to meet emission levels at or near statutory levels in the near term. Reduction of HC and CO emissions from the BMW 3-way system will apparently have to be their prime concern. Since they supplied no details on 3-way catalyst system selection and optimization programs, it remains unclear how BMW plans to obtain low emissions and good fuel economy in the future.

7.3.2. British Leyland (BL)

7.3.2.1. Systems Under Development

BL cites the uncertainty of the 1978 emission standards as a difficulty in concentrating on one particular emission control system. For 1978, BL intends that one of two courses of action will be taken; either to use carryover of existing 1977 systems, or for certain vehicle models to use a 3-way catalyst with a feedback fuel injection system. BL indicates that beyond 1978 all their divisions exporting to the U. S. are working on 3-way catalysts with feedback fuel injection since at the present this system appears to be the most technically desirable solution from BL's viewpoint. BL is actively developing feedback carburetion to offset the cost of fuel injection which BL indicates is too high (approximately $260, according to BL).

Oxidation Catalysts

During the past year BL has investigated newer oxidation catalyst substrates and thermal insulation in hopes of improving catalyst warm-up, efficiency, and durability. They have been successful with durability and efficiency, but still have difficulties with their large vehicle's warm-up characteristics. BL's work with metallic substrates has produced one substrate with a satisfactory material but an insufficiently active and durable catalyst, while the second substrate has a poor material but a satisfactory catalyst. BL plans to incorporate the beneficial characteristics of both of these catalysts into their 3-way catalyst work.

BL continues to experiment with thermal insulation between the catalyst substrate and the catalyst container. Work continues to optimise and select an insulation material suitable for production.

BL indicates that oxidation catalysts have no future below 1.5 gm/mi NOx levels either by themselves or in combination with reduction catalysts. Fuel economy problems with dual catalyst systems were given as part of the reason.

BL will be testing the effects of MMT on their oxidation catalysts.

No further work is being carried out with manifold catalysts.

3-Way Catalysts

Three-way catalyst systems are under active development for all British Leyland models planned to be marketed in the U. S. after 1978. BL anticipates that at least one model (unspecified) will be equipped with a 3-way catalyst for the 1978 model year and probably others for the 1979 model year. The 3-way catalysts tested have a Pt/Rh ratio range from about 3/1 to 12/1.

BL reports that some vehicles will be fitted with fuel injection for reasons of fuel economy and performance, and that on these vehicles the extra cost of the feedback system required is not excessive. In the case of smaller, cheaper vehicles currently fitted with carburetors, the additional cost of feedback fuel injection is considerable. For this reason two other types of system are being investigated in addition to conventional fuel injection and feedback fuel injection.

The first alternative is feedback control of carburetors. This program is being pursued in two areas: firstly, in co-operation with the current outside supplier of carburetors and secondly, as an internal program with a BL carburetor division and an outside electrical supplier. The fuel injection required for the main program of 3-way catalyst work is being actively pursued in conjunction with several European and British manufacturers.

A research program is examining a third alternative, i.e., normal carburetion plus a 3-way catalyst followed by an oxidation catalyst fed with air by an air pump. BL reported no test results or durability data for a 3-way plus oxidation catalyst system.

BL revealed that they have an extensive 3-way catalyst screening process underway with several catalyst manufacturers, and a 3-way catalyst development program with one catalyst manufacturer. BL is impressed with the oxygen storage components of some of the catalysts. BL also noted that catalyst warm-up was still a problem and this produced cold start driveability problems.

Testing to date has concentrated on determining the effect of metal loading, rhodium content, oxygen storage capacity, etc. with a vehicle equipped with a 2 litre engine for emission testing and on 4.2 litre engine for durability testing. More promising catalyst candidates are scheduled for further work.

Typical 4,000 mile results for a 250 CID six cylinder engine with a current best 3-way catalyst are 0.3 - 0.6 HC, 4.5 - 7.0 CO, and 0.6 - 1.0 NOx. Poor warm-up characteristics with this catalyst have been a problem. Further optimization of the catalyst sensor location is underway on this catalyst system.

BL notes that there is a significant improvement in fuel economy by using a 3-way catalyst system. They report urban fuel economy of 14.3 MPG compared with '77 Federal levels of 12.9 and '77 California levels of 12.1 MPG_u. Current European specification vehicles give 14.4 MPG_u but have a slightly higher compression ratio than U. S. versions.

A durability test of 20,000 miles has shown BL that 3-way catalysts have little emission deterioration although the emission levels were reported at 0.57 HC, 7.30 CO, and 1.3 NOx. Armed with this knowledge and a zero mile test on a 120 CID four cylinder engine of 0.10 - 0.20 HC, 1.5 - 3.0 CO, and 0.1 - 0.4 NOx, BL indicates that further intensified work is necessary with this concept.

Dual Catalysts

Only one dual catalyst durability test was conducted by BL last year. According to BL, efforts toward developing this concept have diminished for two reasons: firstly, a reduced interest on the part of catalyst suppliers, and secondly, the increased effort being put into 3-way catalysts and the associated feedback fuel injection systems.

The results of the dual catalyst durability test are shown in Table BL-1; but it should be stressed that this test run involved more than the permitted amount of maintenance for certification testing. The NOx result was 0.35 gm/mi which is too near the 0.4 NOx standard to be considered acceptable to BL, particularly in view of the additional maintenance involved. The HC and CO results were much less impressive, particularly for CO. Even taking only the results for the second oxidation catalyst (after a change at 18,600 miles) the CO level was 13.4 gm/mi. The fuel economy on the urban cycle was 15-16 MPG$_U$ for a 2,500 lb. IW Marina. A total catalyst volume four times that of the current oxidation volume typical for that engine family was used.

A second series of tests at zero miles was carried out on a vehicle with a V12 engine. The best results were 0.73 HC, 4.78 CO, and 0.53 NOx. This vehicle used a total catalyst volume twice that of the "oxidation only" system, whereas the Marina used a factor of four times the volume. The fuel consumption of this system was 8.6 MPG$_U$ for the urban driving cycle compared with 10 MPG$_U$ for the current oxidation only system and a similar figure for a prototype 3-way catalyst system. All systems used fuel injection, the last system incorporating feedback control.

Table BL-1

Dual Catalyst Durability Results

Vehicle: 1.8 litre Marina, EGR, 1976 California specifications
Oxidation catalysts: 2 Johnson-Matthey 206 catalysts, 4" diameter x 4 1/2" long
Reduction catalyst: NM 201 I.C.I
Copper-Nickel-Platinum catalyst, Corning 300 cell substrate, 4" diameter x 4 1/2" long

	FTP Results (gm/mi)				
Miles (10^3)	HC	CO	NOx	MPG_M	Remarks
0	0.16	3.2	0.15	16.5	
7	0.38	4.8	0.22	15.4	
18	0.88	12.4	0.31	14.8	Before Cat. change
19	0.10	3.6	0.35	14.2	After Cat. change
27	0.36	7.5	0.32	14.2	Before Maintenance
27	0.32	4.5	0.43	14.1	After Maintenance
32	0.31	12.4	0.30	15.1	Before Maintenance
32	0.43	6.5	0.35	15.4	After Maintenance
41	0.48	6.6	0.35	16.0	Before Maintenance
41	0.25	3.1	0.36	15.7	After Maintenance
51	0.45	4.0	0.28	15.9	

BL considers the dual catalyst system as a backup to the 3-way system, the only advantage being initial cost on vehicles which have carburetion rather than fuel injection, according to BL.

Other Systems

British Leyland has stopped work on rich thermal reactor systems because of poor fuel economy. They have reduced their efforts with lean thermal reactor systems, and only consider this system for use with their European and stratified charge engines.

Work on the Shell Vapipe has been stopped. A concept which is similar to the Vapipe is being considered.

BL is improving their analytical capabilities to measure non-regulated pollutants.

A sulfate trap consisting of calcium carbonate pellets was tested for 17,000 miles on a 110 CID engine. There was no loss of the absorbent after the accumulated mileage. Further tests are in progress.

BL is working on a transonic carburetor, a sonic idling carburetor, as well as a feedback carburetor. No emissions or fuel economy data were presented for these concepts.

Other Development Concepts

Research work has continued on the three-valve stratified charge engine which was previously reported. BL noted that the three valve engine has higher HC emission than practical for reduction by use of thermal reactors. BL reported that hot engine driveability is good, but cold start and warm-up conditions need refinement.

Typical emissions from this engine are 8.0 HC, 9.0 CO, and 0.50 NOx. These HC results are an order of magnitude higher than those reported by other manufacturers examining the three-valve stratified charge engine. However, most other manufacturers have used some form of aftertreatment such as thermal reactors or catalysts. The fuel economy was 23 MPG_u. By comparison, a similar size and weight vehicle gave approximately 16 MPG_u with dual catalysts and up to 23 MPG_u in the 3-way catalyst configuration.

Further work continues with the three-valve stratified charge concept on another engine type, but unfortunately the HC emissions were also high on this engine. Basic research on this concept continues.

BL has done work with a high compression ratio engine (12:1), but has reported high HC emissions. BL does not plan to introduce this concept in the U. S. unless they can achieve statutory NOx levels with the use of a lean mixture only.

Little work has been reported on Diesel engines by BL. A research program is aimed at achieving NOx levels below 1.0 gm/mi without increased smoke or HC levels. This work investigates injection timing, EGR, and high fuel injection rates.

BL provided no cost or lead time information.

7.3.2.3. Systems to be Used at Various Emission Levels

While not entirely clear from the BL submission, BL apparently intends to use their 1977 emission control system of EGR, oxidation catalysts, air injection, and fuel injection on specific models. For future emission levels, BL apparently will introduce a 3-way catalyst system with fuel injection as a first choice and feedback carburation as a second choice.

Attached to BL's submission was their response to NHTSA's request for a fuel economy position. Table BL-2 indicates the fuel economy penalties/improvements BL associated with various proposed emission levels.

7.3.2.3. Durability Testing

BL provided the durability data listed in Tables BL-3 and BL-4.

7.3.2.4. Progress and Problems

BL has made progress since last year with their 3-way catalyst system, adoption of fuel injection for some vehicle models, and refinement of their oxidation catalyst. While these efforts are encouraging, the data presented by BL also indicate that further efforts are necessary to achieve statutory emission levels. Data from the 3-way catalyst testing indicate that on their larger displacement engines work must be conducted to bring NOx levels closer to the required levels. HC and CO levels on the smaller displacement engine remains higher, thereby reducing confidence in achieving the required control during the entire durability test. Fuel economy improvements are encouraging.

Whether BL will be able to meet statutory emission levels in the near future is impossible to determine with the information that was supplied. To date, it appears that the early 1980s is the most optimistic date of that occurrence.

Table BL-2

Fuel Economy Effects at Various Emission Levels*

		MPG_c Improvement over Previous Model Year	
MODEL YEAR 1976	Emission Targets	1.5 HC, 15 CO, 3.1 NOx	1.5 HC, 15 CO, 3.1 NOx
Less than 4 Seats	Models: MG Midget, Tr Spitfire MGB, TR6 and TR7 2V		
	MG Midget - higher compression	+3 MPG	
	TR Spitfire - higher compression	+3 MPG	
4 Seats	Models: Jaguar XJS		
5 Seats	Models: Jaguar XJ6 and XJ12		
	XJ6 (small engine changes)	+1 MPG	
MODEL YEAR 1977		1.5 HC, 15 CO, 2.0 NOx	1.5 HC, 15 CO, 2.0 NOx
Less than 4 Seats	Models: MG Midget, Tr Spitfire, MGB, TR7 2V and TR7 V8 (Production ends on TR6)		
	MG Midget) Lower compression &	-2 MPG	
	Tr Spitfire) Catalysts fitted for emissions	-2 MPG	
	TR7 2V) Engine tune changed and	+1 MPG	
	MGB) Catalysts fitted for TR7 V8 (new model) special version of TR7 with 3.5 litre V8 engine fitted in place of 2 litre 4 cyl. fuel consumption difference 5 MPG less for V8.	-3 MPG	
4 Seats	Model: Jaguar XJS (no change)		
5 Seats	Models: Jaguar XJ6 and XJ12 (no change)		

Table III-2 (con't)

MODEL YEAR 1978		1.5 HC, 15 CO, 2.0 NOx	0.41 HC, 3.4 CO, 0.4 NOx
Less than 4 Seats	Models: MG Midget, TR Spitfire, MGB, TR7 2V, TR7 V8 (no change)		
	MG Midget)		-2 MPG
	Tr Spitfire) Large change in		-4 MPG
	MGB) severe emission		+1 MPG
	TR7 2V) standards hence		-1 MPG
	TR7 V8) MPG changes		-2.5 MPG
4 Seats	Models: Jaguar XJS (no change)		
	XJS		-0.3 MPG
5 Seats	Models: Jaguar XJ6 and XJ12 and Rover 3500 (SD1) (new model)		
	XJ6 (now on FI)	+2 MPG	+2 MPG
	XJ12		-0.3 MPG

Rover 3500 (SD1) Compare with XJ6 (note not in competition)

Inertia Weight Rover 3500 lbs Jaguar 4500 lbs

Engine Size Rover 3.5 litre V8 Jaguar 4.2 litre 6 cyl

Fuel consumption Rover .9 MPG Jaguar 16 MPG

Table XI-2 (con't)

		1.5 HC, 15 CO, 2.0 NOx	0.41 HC, 3.4 CO, 0.4 NOx
MODEL YEAR 1979			
Less than 4 Seats	Models: MG Midget, Tr Spitfire, TR7 2V, TR7 V8 (Production ends MGB)		
	TR7 2V) Both change to TR7 V8) Petrol injection	+3 MPG +3 MPG	+4 mpg +5.5 MPG
4 Seats	Models: Jaguar XJS and Lynx (new model)		
LYNX compare XJS (note not in competition)			
Inertia Weight	LYNX 3000 lbs Jaguar 4500 lbs		
Engine Size	LYNX 3.5 Litre V8 Jaguar 5.3 liter V12		
Fuel Consumption	LYNX 19 MPG Jaguar 11 MPG		
5 Seats	Models: Jaguar XJ6 and XJ12 Rover 3500 (SD1) (no change)		

		0.9 HC, 4.0 CO, 2.0 NOx	0.41 HC, 3.4 CO, 0.4 NOx
MODEL YEAR 1980			
Less than 4 Seats	Models: Tr Spitfire, TR7 2V, TR7 V8 (Production ends MG Midget)		
	TR Spitfire (more severe lenient emissions)	-1 MPG	
4 Seats	Models: Jaguar XJS and LYNX (no change)		
5 Seats	Models: Jaguar XJ6 and XJ12 and Rover 3500 (SD1) (no change)		

* BL's Submission to NHTSA Request for Fuel Economy Effects at Various Emission Levels.

Table XL-3

XL 3-Way Catalyst Selection Emission and Fuel Economy Durability Data

XJ 7 Vehicle with Fuel Injection, O_2 Sensor, 3-Way Catalyst
Approximately 2500 miles

VIN	Catalyst	HC	CO	NOx	MPG_u
ACL 2	"A"	0.155	2.85	0.29	20.0
ACL 2	"A"	0.12	2.85	0.40	20.7
ACL 2	"A"	0.125	2.45	0.27	20.9
ACL 693	"A"	0.11	3.30	0.43	20.8

1978 Federal and California XJS (Jaguar) Vehicles at 4000 Miles

VIN	Catalyst	HC	CO	NOx	MPG_u
XJ31-22	"A"	0.55	7.93	1.21	13.2
"	"A_1"	0.37	5.63	1.15	13.4
"	"A_2"	0.32	3.69	0.61	14.4
"	"A_3"	0.35	3.87	0.66	14.5
"	"A_4"	0.34	3.80	0.43	13.7

1979 XJ12 (Jaguar) Vehicles at 400C Miles

VIN	Catalyst	HC	CO	NOx	MPG_u
XJ32-7	"A"	3.61	7.7	1.35	9.3
"	"A_1"	0.49	5.4	0.85	16.2
"	"A_2"	0.48	4.4	1.1	9.8

Table BL-4

BL 1977 Model Year Durability Vehicle Emissions and Fuel Economy

VIN/CID	Trans.	System	Mileage (10^3)	FTP Results (gm/mi) HC	CO	NOx	Fuel Economy MPG$_u$
TR7*	M4	OC/EGR/AI	0	0.30	3.61	1.64	19.5
MBF 277P		EM2/2DG	50	0.85	5.75	1.56	18.3
(122 cu in.)			50***	0.70	4.40	1.31	22.4
TR7*	M4	OC/EGR/AI	0	0.36	3.59	1.79	21.3
MBW 278P		EM2/2DG	50	0.73	3.55	1.55	22.8
(91 cu in.)							
TR7-V8*	M5	OC/EGR/AI	0	0.37	1.30	1.55	13.3
MBW 273P		EM23/2DG	50	0.51	3.45	1.13	14.3
(215 cu in.)							
TR7**	M4	OC/EGR/AI	0	0.23	4.21	1.10	18.3
DE 576P		EM2/2DG	50	0.35	6.11	1.39	20.6
(122 cu in.)							
TR7-V8**	M5	OC/EGR/AI	0	0.14	4.55	0.64	11.7
DE 577P		EM2/2DG	50	0.32	6.91	0.56	14.9
(215 cu in.)							
Spitfire**	M4	OC/EGR/AI	0	0.24	1.45	1.26	18.7
MBW 274P		EM2/2DG	50	0.60	4.12	0.96	21.6
(91 cu in.)							
Spitfire**	M4	OC/EGR/AI	0	0.26	2.82	1.63	17.6
MDV 533P		EM2/3C/4	50	0.67	5.96	1.36	20.0
(91 cu in.)							

Table III-4 (cont)

VIN/CID	Trans.	System	Mileage (10^3)	FTP Results (gm/mi) HC	CO	NOx	Fuel Economy MPG_u
TR7*** MDV 532P (122 cu in.)	M5	OC/EGR/AI EM2/3C/4	0 50	0.44 0.81	4.52 6.80	1.67 1.35	21.1 20.3
XJ6 Fed. XJ33-11 (258 cu in.)	A	AI/OC/EGR	5 50	0.46 0.40	3.43 3.00	2.66 2.01	15.8 13.5
XJ12 Fed. XJ 32-31 (326 cu in.)	A	FI/AI/EGR/OC	5 5	0.71 0.65	5.56 6.30	1.76 1.71	9.6 10.0
Rover 3500 S	-	EM 20/3C	25	0.60	1.10	0.36	-
TR7-V8 ACL 391	-	EM 23/20/4	15	0.70	0.79	1.82	-
Rover V8 ACL 444	-	EM 23/20C/4	50	0.91	2.73	1.86	-

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* 1977 Federal Specifications 1.5 HC, 15 CO, 2.0 NOx
** 1977 California Specifications 0.41 HC, 9 CO, 1.5 NOx
*** EPA Test

7.3.3. Citroën

7.3.3.1. Systems Under Development

3-Way Catalysts

Citroën's current efforts utilizing 3-way catalyst systems include fuel injection with feedback control by an oxygen sensor. No data were presented because it is claimed these efforts are not at a stage where results are meaningful.

Other Systems

Citroën has a Diesel engine option for one of its currently manufactured European vehicles. Table Citroën-1 includes emission and fuel economy results from such a vehicle. The 3500 IW vehicle is equipped with a 4 cylinder, 2.5 litre engine and a manual transmission. No information about the emission control system, if any, on the vehicle was reported. This vehicle was involved in a correlation program with EPA.

Table Citroën-1

Citroën Diesel Results

Lab	Exhaust Emissions (gm/mi) HC	 CO	 NOx
Citroën	0.37	1.65	1.59
Citroën	0.37	1.51	1.61
EPA	0.46	1.72	1.46
EPA	0.39	1.75	1.61

Lab	MPG_u	Fuel Economy MPG_h	MPG_c
EPA	25.5	32.2	28.1
EPA	24.2	31.9	27.2

7.3.3.2. Systems to be Used at Various Emission Levels

0.41 HC, 3.4 CO, 0.4 NOx

A 3-way catalyst system is under development to meet these emission levels. No data were presented. The Diesel engine described above is another candidate to meet these levels but substantially better NOx control will be required.

7.3.3.3. Durability Testing

No durability testing was reported.

7.3.3.4. Problems and Progress

Citroën does not now market vehicles in the U.S. and does not intend to do so in the immediate future. All of Citroën's efforts are concentrated on meeting statutory standards. Since no data were presented for their candidate 3-way catalyst system, no progress can be reported.

For their Diesel engine, Citroën feels that a NOx standard below 1.5 gm/mi could not be met in the immediate future on production vehicles, that a 1.0 gm/mi NOx standard would require extensive research with unpredictable results, and a 0.4 gm/mi requirement can simply not be achieved. They have imposed a temporary moratorium on Diesel emissions research until promulgation of definite, stabilized standards at which time they will reevaluate their Diesel program. Without detailed information concerning the type of the emission controls used with the Diesel, little can be stated as to the nature of problems confronting Citroën.

7.3.4. Daimler-Benz

7.3.4.1. Systems Under Development

The Daimler-Benz (DB) status report submission indicated that DB anticipated that the 1977 emission standards would be applicable in 1978. Consequently, DB will be ultilizing many of the systems found on their 1977 model year vehicles. A review of these systems will be detailed under the section on various systems to be used at various emission levels. DB reported development progress on some specific systems, namely the 3-way catalyst system, while providing only scant details on other systems.

Oxidation Catalysts

DB plans to use their present oxidation catalyst through levels of 0.41 HC, 3.4 CO, 2.0 NOx. DB reported no new programs to improve their oxidation catalysts. The results of DB's efforts using oxidation catalyst technology can be found in Table DB-1. With the exception of the M115, M110 California, and Diesel engine families, the remaining vehicles utilize only oxidation catalysts. DB will have no difficulty achieving emission levels down to 0.9 HC, 9 CO, 2.0 NOx with this technology on most of their low altitude vehicles.

3-Way Catalysts

DB provided data outlining their selection process for determining a production-feasible 3-way catalyst for model year 1979 vehicles. They did state, however, that the selection was not finalized nor had the questions concerning O_2 sensor durability needed for closed loop 3-way operation been resolved. DB stated that further work was necessary for system optimization. Research vehicle low mileage test results can be found in Table DB-2 while the 3-way durability results can be found in

Table 19-1

Certification Durability and Data Vehicle Emission and Fuel Economy Results

Engine Family	Mileage (10^3)		FTP Results		Fuel Economy	
		HC	CO	NOx	MPG_U	MPG_H
M115, Carb.	5	0.30	4.4	1.29	17.67	-
INC,AI,EGR	50	0.34	5.0	1.40	18.41	-
(141 CID)	Range	0.25-.37	4.2-5.8	1.29-1.48	17.38-18.49	-
Low Alt.	4	0.23	4.8	0.96	17.2	20.6
High Alt.	4	0.48	12.2	0.99	15.8	-
M110, FI	5	0.62	5.9	1.80	14.75	-
OC,AIR,EGR	50	0.85	9.5	1.74	15.38	-
(168 CID)	Range	0.62-.90	5.9-10.0	1.52-1.97	14.62-15.45	-
49-state						
Low Alt.	4	0.58	4.7	1.56	14.3	19.8
Low Alt.	4	0.57	4.2	1.71	14.6	18.5
High Alt.	4	0.99	5.2	1.77	13.2	18.2
M110, FI	5	0.30	3.1	1.26	14.54	-
TWC,AIR,EGR	50	0.36	4.6	1.36	15.50	-
(168 CID)	Range	0.29-.40	3.0-5.6	1.12-1.48	14.30-15.90	-
Calif.						
Low Alt.	4	0.37	1.6	1.20	14.5	18.1
Low Alt.	4	0.38	1.7	1.08	14.7	18.8
High Alt.	4	0.49	11.9	1.02	13.3	-

Table IX-1 (cont'd)

Engine Family	Mileage (10^3)	FTP Results			Fuel Economy	
		HC	CO	NOx	MPG_c	MPG_h
MI17, FI AIR,OC,EGR (276 CID) 49-state, Hi Alt. Calif.	5	0.56	6.2	1.82	11.22	-
	50	0.77	7.0	1.76	12.17	-
	Range	0.49-.77	6.2-7.1	1.60-1.93	10.96-12.17	
Low Alt.	4	0.30	5.2	1.72	12.0	18.3
High Alt.	4	0.39	3.6	1.75	12.5	20.0
MI17, FI AIR,OC,EGR (276 CID) 49-state	5	0.52	5.5	1.72	11.76	-
	50	0.70	7.3	1.71	12.86	-
	Range	0.51-.75	5.4-7.7	1.45-1.91	11.52-12.86	-
Low Alt.	4	0.87	5.2	1.69	13.2	20.5
MI17, FI,AIR OC,EGR (276 CID) Calif.	5	0.27	3.6	1.47	11.26	-
	50	0.36	5.0	1.42	12.46	-
	Range	0.27-.40	3.6-5.4	1.30-1.50	11.25-12.46	-
Low Alt.	4	0.26	1.7	1.30	12.0	17.3
High Alt.	4	0.34	5.1	1.25	12.3	20.2
MI17, FI,AIR OC,EGR (276 CID)	5	0.27	4.1	1.39	11.35	-
	50	0.35	5.1	1.31	12.65	-
	Range	0.22-.40	3.8-5.6	1.28-1.50	11.35-13.25	-

Table 18-1 (con't)

Engine Family		Mileage (10^3)	FTP Results HC	FTP Results CO	FTP Results NOx	Fuel Economy MPG_U	Fuel Economy MPG_H
Low Alt.		4	0.25	2.7	1.28	22.8	27.6
High Alt.		4	0.39	7.4	1.04	21.8	-
MSG4, FI		5	0.27	3.4	1.43	10.36	-
AIR,OC,EGR		50	0.36	6.1	1.42	10.56	-
(417 CID)	Range		0.27-.38	3.4-6.1	1.31-1.47	9.6-11.47	-
Low Alt.		4	0.25	3.8	1.25	10.5	14.3
High Alt.		4	0.23	2.1	1.59	10.1	14.5
OM616		5	0.30	1.7	1.40	23.75	-
Diesel (240D)		50	0.34	1.6	1.27	20.05	-
50-state	Range		0.27-.34	1.5-2.1	1.27-1.51	20.05-26.03	-
(147 CID)							
Low Alt.		4	0.36	0.9	1.65	25.9	30.2
High Alt.		4	0.35	1.5	1.62	25.3	-
Low Alt.		4	0.37	1.2	1.43	24.8	33.5
OM617		5	0.25	1.3	1.85	24.30	-
Diesel (300D)		50	0.20	1.1	1.70	22.75	-
50-state	Range		0.19-.25	1.1-1.[illegible]	1.67-1.85	21.85-24.30	-
Low Alt.		4	0.29	1.0	1.70	22.2	-
High Alt.		4	0.48	1.4	1.81	22.9	-

Table 18-2

DB 3-Way Catalyst plus O_2 Sensor Research-Vehicles Emission and Fuel Economy Data

VIN	CID	Emission Target	No. of Tests	Average FTP Results			Fuel Economy	
				HC	CO	NOx	MPG_u	MPG_h
R107-E45-66	276	2	4	1.124	17.689	1.242	11.61	-
*		2	7	0.718	3.75	0.320	12.47	18.42
W116-E69-139	417	2	2	0.814	15.05	0.882	10.23	-
*		2	7	0.399	4.32	0.348	10.78	-
W116-E69-35	417	3	1	0.381	3.536	0.867	10.67	15.12
W116-E45-113	276	3	15	0.304	2.956	0.580	12.35	-
R129-E45-51	276	4	1	0.186	3.173	0.338	11.93	19.01
W116-E28-97	168	4	2	0.337	2.987	0.243	15.83	20.58

Targets

1 = 1.5 HC, 15 CO, 2.0 NOx
2 = 0.41 HC, 9 CO, 1.5 NOx
3 = 0.41 HC, 3.4 CO, 1.0 NOx
4 = 0.41 HC, 3.4 CO, 0.4 NOx

Table DB-10 in the system durability section. No mileage is specified for the durability test results, nor were there any durability vehicles targeted for emission levels lower than 0.41 HC, 9 CO, 1.5 NOx.

3-Way Plus Oxidation Catalyst

DB provided no discussion of their efforts with a 3-way catalyst plus oxidation catalyst system. However in their data submission the following data from a research vehicle was noted.

Table DB-3

Data from Research Vehicle R107-E45-51 (450SL,276CID)
Equipped with a EFI/O_2S/TWC/AI/OC System
Targeted at 0.41 HC, 3.4 CO, 1.0 NOx

	FTP Results (gm/mi)			Fuel Economy	
Date	HC	CO	NOx	MPG_u	MPG_h
3-26-76	0.105	2.532	0.606	13.54*	17.80**
4-6-76	0.289	2.533	0.505	13.92	
4-8-76	0.324	2.806	0.585	13.78	
4-12-76	0.316	2.955	0.519	13.75	
4-21-76	0.290	2.312	0.814	14.15	
4-22-76	0.299	2.746	0.592	14.05	
4-23-76	0.308	2.965	0.517	13.89	

* Fuel economy improvement over current engine families.
** Average two tests.

It is evident that further work is necessary to reduce the NOx levels from this system if 0.4 NOx is to be achieved with this approach. DB reported test data from one vehicle (W114 V28-156) which incorporated EGR and air injection with a 3-way catalyst. NOx levels remained high (3 gm/mi) while there was a fuel economy improvement of 3 MPG_u for this vehicle. Work was stopped on this concept in April 1976. No reason was given.

Dual Catalysts

DB uses a system containing a reduction catalyst on some 1977 model year vehicles and plans to continue this practice into 1978. A description of their production dual catalysts can be found in the footnotes to Table DB-9. A review of DB's flow curves in their Part I submitted to the Certification Division apparently indicates that those engine families which use the dual catalyst system are calibrated lean. These flow curves were for part load operation and indicated production tolerance A/F ratios between 15.2 to 17.0. If the flow curves are correct, it is difficult to determine how DB expects to maintain a reducing atmosphere thereby enabling the reducing catalyst to function properly. The reducing portion of the dual catalyst may be used during those portions of vehicle operation on the FTP when the air-fueled ratio has an excursion to the rich side of stoichiometric, thereby creating a reducing atmosphere. DB did not provide enough discussion to ascertain the reason for the expected results or technical discussion on the selected catalysts to make a judgement on the benefit of the system. A review of the certification data in Table DB-1 apparently indicates that the M110 family with the dual bed catalyst has lower NOx emission levels than the same family with an oxidation catalyst. It is difficult to determine if this system has potential below 1.0 gm/mi NOx, however.

Dual Bed catalyst research vehicle data can be found on Table DB-4 and the durability results in Table DB-11. There were no durability mileages given.

Table DB-4

DB Dual Bed Catalyst Research Vehicle Emission and Fuel Economy Data

				Avg. FTP Results			Fuel Economy	
VIN	CID	Emission Target	No of Tests	HC	CO	NOx	MPG_u	MPG_h
W115 V23-130	141	2	41	0.248	3.64	1.093	15.29	-
W116 B45-62	276	4	4	0.200	1.564	0.374	11.05	-

Targets

1 = 1.5 HC, 15 CO, 2.0 NOx
2 = 0.41 HC, 9 CO, 1.5 NOx
3 = 0.41 HC, 3.4 CO, 1.0 NOx
4 = 0.41 HC, 3.4 CO, 0.4 NOx

Other System Developments

Stratified Charge Engine

DB did not discuss their work on this engine concept in their submission. They did present data on this engine are is detailed in the following table.

Table IB-5

DB Stratified Charge Engine Tests

Veh.	CID	EC System	Target Stds.	No. of Tests	Average FTP Results			Fuel Economy	
					HC	CO	NOx	MPG$_u$	MPG$_h$
W115 VIN-122 MB240	1-4/167	CIS/O$_2$S/TWC	0.41 HC, 3.4 CO, 1.0 NOx	10*	0.257	4.63	0.974	19.82	22.33**
W115 VIN-240	1-4/167	Pt/Rh Cat.	0.41 HC, 3.4 CO, 1.0 NOx	10+	0.576	0.980	1.49	20.25	21.57***

* Hot Start Tests

** 10 tests

*** 9 tests

+ None of the tests achieved target emission levels

The tests of Table DB-5 were conducted over the period of one year and reveal a potential for low HC and CO control with an approximately 18% urban cycle fuel economy gain over the present engine in the MB 240 model vehicle. DB did not provide sufficient details to properly evaluate this concept.

Diesel Engines

Daimler-Benz has been one of the leaders in the production of Diesel engine powered automobiles since the 1930s. Their 240D and 300D series vehicles along with the Peugeot vehicles have been the only Diesel powered vehicles available in the U.S. However, the introduction of Diesel powered vehicles by GM and Volkswagen may increase the competition in this area.

Up to now, DB has steadfastly insisted that the NOx barrier of 1.5 gm/mi would preclude the mass introduction of Diesel vehicles in inertia weight classes above 3500 pounds IW. The development work necessary to lower NOx emission below 1.5 NOx necessitates use of other concepts besides the simple reverse flow damping valve currently used in the DB injection system. DB did provide information on both the use of EGR and turbocharging of their Diesel engines.

Diesel EGR Concepts

DB reported on two modulated EGR concepts for their Diesel engines targeted at achieving 1.0 gm/mi NOx. These concepts are the differential pressure control system and the air fuel ratio control system.

1) Differential Pressure Control System

The exhaust manifold and intake manifold are connected by an EGR pipe which can be closed by an EGR valve mounted at the exhaust manifold. The EGR valve is operated by a vacuum motor. The recirculation rate is determined by the pipe diameter and the valve lift, depending on the differential pressure of the intake manifold and the exhaust manifold.

The vacuum motor is loadeu by a pneumatic pilot valve which in turn is governed by a lever. At a lever position corresponding to 4/5 load, the pressure on the valve is released and vacuum valve is closed by a spring. At cold start there is no EGR. Results to date range from 0.5 to 0.7 NOx on a laboratory basis. DB reports a corresponding HC rise and significant CO and smoke increase with this system. Fouling of the intake manifold and lubrication oil was also reported. There has been no durability testing of this system.

2) Air Fuel Ratio Control System

DB is working in cooperation with Bosch to develop an EGR system which operates in principle as an air fuel ratio (Lambda) control. DB describes the system thusly:

"This EGR system consists of fuel and air metering devices which are actuated by a servo assisted throttle valve. A modified fuel pump produces the servo pressure which is needed to actuate the throttle valve.

Thus, in dependence of the fuel flow of the injection pump, a coordination between injected fuel amount and aspirated air volume can be realized, and for the smallest lambda which is possible, the reduced air volume can be substituted by exhaust gas. At full load, there is no EGR.

The adjustment of the air volume meter at idle speed will be done in dependence of the CO_2 volume of the exhaust gas.

At testing of such a pilot system, analogous experiences as described in the EGR system before, were noted. Under actual driving conditions, and special consideration of good engine starting, smoke emission and diesel knocking, NOx emission values from 0,7 .... 0,8 gm/mi can be reached as an optimum.

Durability results from this system are not available, since this prototype had many corrections, and maintenance jobs required."*

Tests results of EGR equipped Diesel engine powered research vehicles can be found in Table DB-6 and the durability vehicle results can be found in Table DB-12 in the durability section.

Turbocharged Diesel Engine

DB has been working on a turbocharged Diesel engine in the recent past. One concept, the Comprex supercharger, has received interest by both DB and EPA. EPA has tested this vehicle and reported the results in an EPA report.** DB is losing interest in this concept and is now concentrating on an unspecified turbocharged version of the 300D series vehicles. These engines are targeted for 1.5 HC, 15 CO, 2.0 NOx and will possibly be introduced in model year 1978. Data from DB research Diesel vehicles targeted at 0.41 HC, 3.4 CO, 2.0 NOx can be found in Table DB-7. DB presented no durability data for these vehicles.

DB displayed data (Table DB-8) which are presented here for comparison purposes with both the aforementioned concepts and other Diesel engine powered light duty vehicles. Details of vehicle calibrations, etc., were not provided by DB. A greater than 10 MPG difference in highway fuel economy exists between two 300D vehicles (W115-D30 276 and W115-D30 116) on Table DB-8, for example. Data to explain this difference were not provided.

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* Daimler-Benz Status Report, October 1976, Vol. 1, pages 77-78.

** Test results on Mercedes-Benz 220D Diesel Sedan equipped with a Comprex Pressure Wave Supercharger, TAEB Report No. 76-2 DB, August 1975.

Table 10-6

Emissions and Fuel Economy Results
From a MB Diesel Powered Research Vehicle
Equipped with EGR

VIN	CID	Emission Target(s)	No. of Tests	FTP Results (gm/mi) HC	CO	NOx	Fuel Economy MPG_u	MPG_h
W115 114-240	147	0.41 HC, 3.4 CO, 2.0 NOx	1	0.169	2.370	0.922	23.96	32.66
W115 110-176	147	0.41 HC, 3.4 CO, 2.0 NOx	11	0.209	2.19	0.926	22.81	29.57*
W115 110-176	183	0.41 HC, 3.4 CO, 1.0 NOx	6	0.225	1.78	0.961	24.67	32.09**
W115 110-256	183	0.41 HC, 3.4 CO, 1.0 NOx	6***	0.167	1.45	1.76	22.04	27.74****

* 8 valid tests
** 13 valid tests
*** None of the tests achieved target emission levels
**** 5 valid tests

Table 3B-7

Turbocharged Diesel Engine Emission and Fuel Economy Data

(Emission Targets 0.41 HC, 3.4 CO, 2.0 NOx)

			Average FTP Results			Fuel Economy	
VIN	CID	No. of Tests	HC	CO	NOx	MPG_U	MPG_H
W116 330A-71	183	25	0.142	0.885	1.57	25.23	35.19*
W123 330A-90	183	2	0.151	1.12	1.35	26.87	35.27
W116 330A-119	183	3	0.086	0.79	1.66	24.81	36.79**
W116 330A-149	183	4	0.098	0.88	1.86	22.97	36.29*

* 3 valid tests

** 4 valid tests

Table 28-8

MB Diesel Power Vehicles

VIN	CID	Emission Targets	Research or Durability Vehicle	No. of Tests	Avg. FTP Results			Fuel Economy	
					HC	CO	NOx	MPG_u	MPG_h
W123 D24-64 (2400)	147	1	R	3	0.085	0.882	1.74	23.16	25.20
W123 D30-294 (3000)	183	1	R	7	0.189	1.33	1.43	22.60	28.90
W115 D30-243 (D3000)	183	1	R	13	0.130	1.24	1.47	22.95	30.10
W115 D30-281 (3000)	183	1	R	1	0.117	1.66	1.73	22.87	30.32
W115 D30-225 (3000)	183	1	D	4	0.132	1.22	1.84	22.81	31.10
W115 D30-273 (3000)	183	1	D	5	0.160	1.64	1.56	24.67	35.17
W115 D30-276 (3000)	183	1	D	3	0.124	1.24	1.64	24.83	36.67
W123 D20-126 (2000)	122	2	R	11	0.102	1.03	1.24	25.64	30.74
W123 D20-136 (2000)	122	2	R	3*	0.527	1.74	1.58	24.99	31.52

Table 3B-8 (cont'd)

VIN	CID	Emission Targets	Research or Durability Vehicle	No. of Tests	Avg. FTP Results HC	Avg. FTP Results CO	Avg. FTP Results NOx	Fuel Economy MPG_u	Fuel Economy MPG_h
W115 129-195 (2000)	122	2	R	2*	0.491	2.17	1.32	22.68	29.43
W115 124-250 (2400)	147	2	R	13	0.158	1.29	1.51	25.36	32.70
W123 130-94 (3000)	183	2	R	3	0.128	1.09	1.67	23.57	26.90
W116 130-116 (3000)	183	2	R	3	0.109	0.78	1.71	25.95	26.40
W115 130-229 (3000)	183	2	R	3	0.223	1.25	1.29	24.23	30.50
W115 130-226 (3000)	183	2	R	2	0.126	1.15	1.79	22.96	29.21
W115 130-236 (3000)	183	2	R	5	0.105	1.07	1.69	23.61	-
W116 130-130 (3000)	183	2	D	8	0.080	0.80	1.72	23.70	27.60

Legend: Emission Targets

1 = 1.5 HC, 15 CO, 2.0 NOx
2 = 0.41 HC, 3.4 CO, 2.0 NOx

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* None of the data achieved target emission levels.

7.3.4.2. Systems to be Used at Various Emission Levels

The Daimler-Benz system that will be used at various emission levels can be found in Table DB-9.

7.3.4.3. Durability Testing

DB provided the durability test results shown in Tables DB-10 through 12. There were no mileage figures given with any of the durability tests, thereby making it difficult to assess their progress in meeting future emission levels.

DB reported a test on a high mileage Diesel vehicle. The vehicle tested was a randomly selected German 300D taxicab. The emissions results were 0.14 HC, 1.3 CO, 1.9 NOx. At the time of the test, the vehicle had 220,000 miles on it.

7.3.4.4. Progress and Problems

Daimler-Benz's progress with 3-way catalyst system lags the progress other foreign manufacturers and some domestic manufacturers have exhibited. While DB has demonstrated the low mileage potential to meet 0.4 NOx, the lack of durability data for this system casts doubts upon its immediate introduction. Because of the poorly described durability data, a projection on lead time for introduction of 3-way catalyst systems on DB vehicles is difficult to make.

Like others, DB's 3-way catalyst systems tests indicate that control of CO will be a problem even at low mileage. This difficulty may be overcome with better 3-way catalyst selection and refined engine calibrations. DB's 3-way catalyst work to date demonstrated no fuel economy penalty for most vehicles and a slight (~0.5 MPG) fuel economy improvement for others. DB will need considerable work with this concept

Table 7B-4

Daimler-Benz Emission Control Systems at Various Emission Levels

Model-Year	Engine Type	Appl.	CID	Ind. System	Engine Mods	EGR	Air Inj.	Dual Cat.	Ox. Cat.	O_2 Sensor	3-way	Turbo
1979 1.5 HC, 15 CO, 2.0 NOx	M115	50 state[a]	141	Carb	X	X	X^b	X^{cd}	-	-	-	-
	M110	49 state	167.5	Bosch K-Jet.	X	X^c	X^c	-	X^d	-	-	-
	M110	Calif.	167.5	"	X	X^e	X^b	X^d	-	-	-	-
	M117	49 state	276	"	X	X	Asp.	-	X^b	-	-	-
	M117	Calif.	276	"	X	X	X	-	X^c			
	M100	50 state	417	"	X	X	X	-	X^c	-	-	-
	OM616	50 state	147	Diesel Inj	Pre Chamber	-	-	-	-	-	-	-
	OM617	"	183	"	"	-	-	-	-	-	-	-
	OM617a	"	183	"	"	-	-	-	-	-	-	$-^f$

Table [illegible] (con't)

Model Year	Engine Type	Appl.	CID	Ind. System	Engine Mode	EGR	Air Inj.	Dual Cat.	Ox. Cat.	O_2 Sensor	3-way	Turbo
1979/80 0.41 HC, 3.4 CO 2.0 NOx	M115	50 state	141	Carb	X	X	X	X	–	–	–	–
	M110	49 state	167.5	Bosch K-Jet.	X	X	X	–	X	–	–	–
	M110	Calif.	167.5	"	X	X	?	X	–	–	–	–
	M117	49 state	276	"	X	X	Asp.	–	X	–	–	–
	M117	Calif.	276	"	X	X	X	–	X	–	–	–
	M100	50 state	417	"	X	X	X	–	X	–	–	–
	OM616	"	147	Diesel Inj	Pre Chamber	–	–	–	–	–	–	–
	OM617	"	183	"	"	–	–	–	–	–	–	–
	OM617A	"	183	"	"	–	–	–	–	–	–	–
1981 0.41 HC, 3.4 CO, 1.0 NOx	M115	50 state	141	Carb	X	X	X	X	–	–	–	–
	M110	"	167.5	Bosch K-Jet.	X	–	X	–	–	?	X	–
	M117	"	276	"	X	–	X	–	–	?	X	–
	OM616	"	147	Diesel Inj.	Pre Chamber	Δ	–	–	–	–	–	–
	OM617	"	183	"	"	Δ	–	–	–	–	–	–
	OM617A	"	183	"	"	Δ	–	–	–	–	–	B

Table DB-9 (con't)

Legend:

a Differs from MY 77 version with regard to breakerless transistorized ignition system, high altitude adjustments and modification to evaporative system.

b Air switched: $t < 62.5^\circ F$ and $t > 122^\circ F$ air is injected ahead of oxidation catalyst $62.5^\circ F < t > 122^\circ F$ air is injected directly into the exhaust port.

c	Reduction Catalyst	d	Oxidation Catalyst
	Platinum + Rhodium		Platinum + Palladium
	1.7 gm Pt 0.73 gm Rh		1.831 gm Pt 0.915 gm Pd
	514 gm		1076 gm
	Monolith		Monolith
	5.78" x 3.03"		5.78" x 3.03"
	2.92" long		6" long
	HSV 58,000 h^{-1}		HSV 35,000 h^{-1}

e BPEGR

f Manifold air injection

g Same loading as M 115 catalysts, only reduction catalysts mounted underhood, oxidation catalyst underfloor

h Vehicle Models M 117/W 116 to use 2 catalysts 6 x 4 693 gm loading same as note d

Vehicle Models M 117/R/C 107 Federal to use one 5.78 x 3.03 x 6 inch catalyst with 1.45 g Pt + 0.17 gm Rh, 1064 gm total loading.

i Larger catalyst volume than Federal version, 1425 g total loading

j May have a turbocharged version

k For MY 80 California version will possibly have no EGR, AIR, and use a 3-way catalyst - not determined yet.

l No details

A Two EGR systems under development
    Differential Pressure Modulated EGR
    Air Fuel Ratio Control Modulated EGR

B "The lower standards for HC and CO emissions can be met with the turbocharged engine in the weight (4000 lbs) class."**

**Daimler-Benz Status Report, page 81.

Table 1B-10

DB Three-Way Catalyst and O_2 Sensor Durability Vehicle Results

Emission Targets 0.41 HC, 9 CO, 1.5 NOx

VIN	CID	No. of Tests	Avg. FTP Results			Fuel Economy	
			HC	CO	NOx	MPG_a	MPG_b
R107 B45-71	276	13	0.313	2.96	0.693	11.71	-
W116 B45-123	276	3	0.313	2.03	0.362	11.73	-
W116 B69-52	417	1	0.062	9.357	0.642	11.26	15.06

before they reach the demonstrated achievement of other manufacturers.

The dual catalyst work, in which DB reported using a NOx catalyst at lean air-fuel ratios, was unusual and differed from conventional practice in this regard. The technology assessment of DB's dual catalyst system remains perplexing due to scarcity of technology descriptions and durability test data.

DB's efforts on the stratified charge engine show fuel economy benefits and potential for emissions levels of 0.41 HC, 3.4 CO, 1.0 NOx. Again, the lack of technical description and further data precludes further discussion of this concept.

The use of EGR on a Diesel engine has been tried by DB and the results to date have been mixed. There are indications that EGR has the potential of lower NOx levels below 1.0 gm/mi without adverse effects on HC, CO, or fuel economy. The effect on smoke levels or particulate emissions cannot be determined from DB's submission. Since DB did not report durability mileages it is impossible to determine the durability effects of EGR.

Also, DB did not reveal any information or data on Diesel engines targeted to meet the statutory levels of 0.41 HC, 3.4 CO, 0.4 NOx. This may have been intentional, since DB steadfastly maintains that 1.5-2.0 gm/mi NOx must be the limit for Diesel powered vehicles. Previous submissions from DB have indicated developmental Diesel powered vehicles have the capability to achieve 0.4 NOx. The lack of any data on Diesel systems targeted toward 0.4 NOx may indicate that DB does not consider this emission level to be a real future requirement.

Table 10-11

10 Dual Bed Catalyst Durability Vehicle Results

Emission Targets 0.41 HC, 9 CO, 1.5 NOx

VIN	CID	No. of Tests	Avg. FTP Results			Fuel Economy	
			HC	CO	NOx	MPG_U	MPG_H
6U15 V23-213	141	2	0.331	1.93	1.24	14.83	-
6U15 V23-222	142	1	0.394	1.45	1.18	15.47	-
6U16 E28-267*	260	3	0.400	1.98	1.24	14.47	-
8207 E28-63*	260	1	0.300	1.57	1.03	12.72	-
8207 B45-72	260	6	0.385	1.36	0.96	13.30	18.19
6U16 B89-74	427	2	0.255	1.40	1.29	10.37	-

---

* EGR also

Table 3B-12

EGR Equipped Diesel Durability Vehicles Emission and Fuel Economy Results

Emission Target 0.41 HC, 9 CO, 1.5 NOx

				Avg. FTP Results			Fuel Economy	
VIN	CID	Emission Targets	No. of Tests	HC	CO	NOx	MPG_u	MPG_h
6115 D30-272	183	0.41 HC, 7.4 CO, 1.0 NOx	7*	0.148	1.17	1.45	23.15	26.99+
6115 D30-275	183	0.41 HC, 3.4 CO, 1.0 NOx	4	0.213	1.41	0.92	24.11	29.04**

---

* None of the tests achieved target emission levels
+ 6 valid tests
** 9 valid tests

7.3.5. Fiat

7.3.5.1. Systems Under Development

3-Way Catalyst Systems

Fiat is apparently doing some 3-way catalyst screening on bench setups and engine dynamometers. Additional evaluations are being conducted on vehicles at "zero" miles to determine the influence of various engine operating conditions on conversion efficiency and in defining the width of the catalyst window. As no data were submitted, no measure of the status of this program can accurately be determined.

Other Systems

Various Otto cycle, 4-cylinder, prechamber engines are currently under development by Fiat, but few details were presented. One mechanically fuel injected, 2000 lb IW, manual transmission vehicle has had preliminary emission levels averaging 1.3 HC, 4.5 CO, 1.2 NOx. Further improvement of the fuel injection system has yielded levels of 1.25 HC, 3.35 CO, 1.2 NOx on this vehicle. No fuel consumption data were reported. A lean reactor system has been designed and is now under construction in an attempt to further reduce HC and CO. A turbocharged version of this engine is currently being installed in a vehicle. Work on a tridimensional cam was reported but no details were presented.

Carbureted versions of the prechamber concept are also under development. Initial results using a 2500 lb IW vehicle have been about 2 HC, 7 CO, 0.9 NOx. With a thermal reactor (uninsulated and without secondary air) results have been about 0.8 HC, 4.5 CO, 0.9 NOx. With a pelleted, noble metal catalyst (without secondary air) results have been about 0.6 HC, 2.5 CO, 0.9 NOx. Further work is being conducted to optimize the calibration between the main and auxiliary carburetors. The most recent engine configuration has a prechamber volume of about 10% of total volume, 8:1 compression ratio, and runs at an average air-fuel ratio of about 18:1. A prototype version of this engine is currently being installed in a 2500 lb IW vehicle. In a parallel effort a new dual chamber thermal reactor is also being constructed. No details or emission data for these recently developed systems were reported.

Other results have been reported in the literature* concerning Fiat's prechamber engine. The engine employs a spherical prechamber which ignites the charge from the center of the prechamber. The naturally aspirated engine yields 105 BMEP, and turbocharging increases this to 150 BMEP. The compression ratio is 11:1. There is no ignition control, the timing is fixed at 5° BTDC. Naturally aspirated, the octane requirement is 77 in terms of primary reference fuels, and the turbocharged engine has an octane requirement of 86. Using Indolene Clear fuel, the emissions were 1.54 HC, 3.75 CO, 1.24 NOx, 26 MPG_U. The engine is also reported to have low noise levels.

Fiat is also studying a thermal reactor for this engine. The thermal reactor has a center tube that is composed of a nickel and copper-containing surface catalyst.

Fiat is also developing three, 4-cylinder, prechamber Diesels of 1.8, 2.0, and 2.4 litres and one 4-cylinder, open-chamber Diesel of 3.5 litres. The 1.8 litre engine is being installed in vehicles of 2250 and 2500 lb IW. Some average emission results from the 2.0 and 2.4 litre prechamber engines are presented in Table Fiat-1.

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* Champion Ignition and Engine Performance Conference, Vienna Austria, 1976.

Table Fiat-1

Average Diesel Results

Engine	Power	IW	FTP emissions, gm/mi HC	CO	NOx	Fuel Economy MPG_u	MPG_h
2.0 litre	60 hp at 4400 RPM	2750	0.53	2.03	0.78	27	34
2.0 litre	60 hp at 4400 RPM	3000	0.41	1.78	1.32	28	36
2.4 litre	72 hp at 4200 RPM	3000	0.76	2.43	1.07	26	35

A total of 13 vehicles, seven 2750 lb IW vehicles (two with manual transmissions) and six 3000 lb IW vehicles, equipped with 2.0 litre engines have satisfactorily accumulated over 30,000 miles in testing designed to study the mechanical reliability of this engine. No emission results were presented.

Fiat also reported work on fumigation for Diesels. Fumigation is the name given to a technique of altering the usual method of introducing fuel in a Diesel engine. In the usual approach, all of the fuel is introduced into the cylinder via the high pressure fuel injection system. Fumigation consist of introducing some of the fuel mixed with air as a premixed charge into the cylinder during the intake stroke, like with a conventional gasoline engine. The rest of the fuel is introduced in the usual manner. Fumigation has the potential to increase the Diesel's air utilization and also to reduce ignition delay. Fiat has tried fumigation on a 2.4 litre, indirect injection engine and a 3.5 litre direct injection engine. Based on the results to date, Fiat concluded:

1. Oxides of Nitrogen can be reduced from 10 to 30%.
2. Wide-cut fuels can be used without losing thermal efficiency.
3. Combustion noise can be appreciably reduced.

Fiat will continue work in this area to find a practical way to obtain the fumigation, and to study the fumigated air-fuel ratio that is best for HC and CO control.

Other Development Efforts

Other efforts include work on a feedback controlled EGR valve, exhaust gas sensors, low thermal inertia exhaust manifolds, and microprocessor controlled electronic fuel injection. Most of these developments represent early efforts and little detail was provided.

7.3.5.2. Systems to be Used at Various Emission Levels

1.5 HC, 15 CO, 2.0 NOx

Fiat's systems for 1978 will be substantially the same as for 1977. These are described in Table Fiat-3. Fiat did not provide any information on systems to meet any other emission standard.

7.3.5.3. Durability Testing

Fiat did not provide any durability test data.

7.3.5.4. Progress and Problems

Other than some encouraging results from Diesel engines and other efforts with prechamber engines, it appears Fiat has much work to do in order to meet any emission level much lower than 1977 California standards (0.41 HC, 9 CO, 1.5 NOx). Fiat's other development efforts are in the early stages of development and they appear to be far behind other manufacturers in many of these same areas, particularly in the area of durability testing of prototype emission control systems. The lack of adequately reported data prevented a more comprehensive assessment of the progress and problems of Fiat.

Table Fiat-2

1979 Emission Control System Descriptions - 1.5 HC, 15 CO, 2 NOx

	Engine	Carb	IW	Trans	Axle Ratio	N/V	Ignition System	EGR	Air Injection	Catalyst
Federal	1,289.7cc 4-cyl 8.5:1 C.R.	2-V Weber	2250, 2500 lb	4-spd man	3.765:1, 4.416:1	61, 58, 72	HEI, mech. and vac. adv.	none	belt driven pump, port injection	none
California	1,289.7cc 4-cyl 8.5:1 C.R.	2-V Weber	2250 lb	4-spd man	3.765:1 4.077:1	61, 66	HEI, mech. and vac. adv.	none	belt driven pump, port injection	DIP underfloor pelleted ox. cat., 1.244 gm Pt, 2.2 litre vol.
Federal	1,755.5 cc 4-cyl 8.0:1 C.R.	2-V Weber	2500, 2750, 3000 lb	5-spd man, 3-spd auto	4.1:1, 4.214:1 4.3:1, 4.357:1, 4.444:1	53, 56, 57, 58, 66	HEI, mech. and vac. adv.	port vac. controlled	belt driven pump, port injection	none
California	1,755.5 cc 4-cyl 8.0:1 C.R.	2-V Weber	2500, 2750, 3000 lb	5-spd man, 3-spd auto	3.909:1 4.1:1, 4.214:1, 4.3:1, 4.357:1 4.444:1	53, 55, 56, 58, 66, 67	HEI, mech. and vac. adv.	port vac. controlled	belt driven pump, port injection	DIP underfloor pelleted ox. cat., 1.244 gm Pt, 2.2 litre vol.

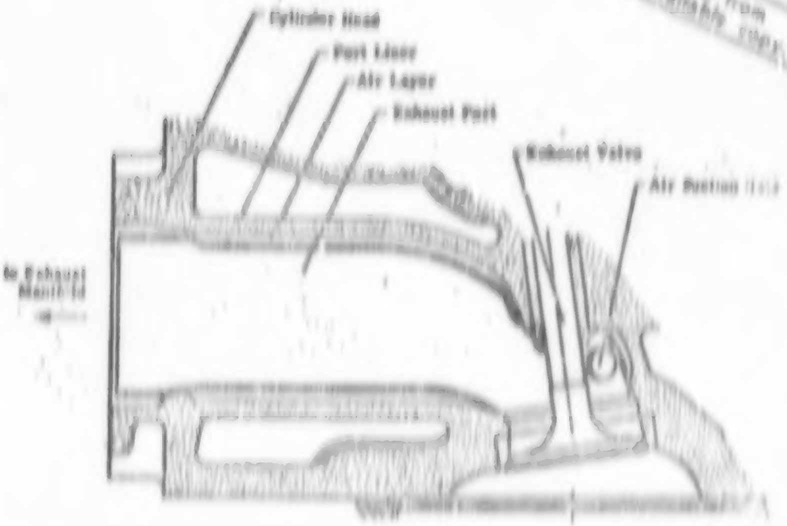
7.3.6. Fuji Heavy Industries (Subaru)

7.3.6.1. Systems to be Used

Fuji departs from conventional technical apprnaches in many aspects of their vehicle engineering. For example, their engine layout, a horizontally-opposed, four cylinder, water cooled configuration is unique. Their emission control systems, likewise, are unconventional. Fuji relies upon heat conservation techniques combined with air injection to control HC and CO. The heat conservation techniques include exhaust port liners along with double wall insulated exhaust manifolding and piping. Fuji's exhaust port liner is shown in Figure Fuji-1. The air injection system utilizes an aspirator valve and injects the air quite close to the exhaust valve for maximum effectiveness. All of these measures serve to promote the after-reaction of HC and CO. A ported EGR system is used to control NOx. Fuji indicates that this non-catalytic system with modification and recalibration of its major components will be capable of meeting emission standards as low as 0.41 HC, 3.4 CO, and 1.0 NOx.

Figure Fuji-1

Reproduced from best available copy



Fuji reported last year on an EGR system designed for the 1.0 NOx level that included two EGR valves: one in the carburetor and another in the intake manifold. No diagrams or detailed information were provided. They now report that this system achieved well below the 1.0 NOx level but at a considerable penalty in driveability and fuel economy. The system appears to have been dropped.

Fuji does not describe any systems targeted at the 0.41 HC, 3.4 CO, 0.4 NOx level but they did indicate that they are considering the 3-way catalyst approach for future emission levels. Their approach would apparently be to combine heat conservation measures with a 3-way catalyst.

7.3.6.2. Systems to Meet Various Emission Levels

Fuji indicates that at the 0.41 HC, 3.4 CO, 2.0 NOx level, they will modify and/or recalibrate their exhaust manifold, distributor, and EGR valve. The air-fuel ratio will be richened to approximately stoichiometric or slightly richer. Fuji did not provide cost information for this system. Table Fuji-1 shows emissions and fuel economy data for this system.

For the 0.41 HC, 3.4 CO, 1.0 NOx level, Fuji will use a slightly rich airfuel ratio combined with heat conservation, AIR (aspirator), and EGR. The major difference between this system and the 2.0 NOx system previously discussed is EGR flow rate, which is substantially higher. Emissions and fuel economy for this system are also shown in Table Fuji-1.

Table Fuji-1

Emission Target	Trans.	HC	CO	NOx	MPG_u	MPG_u*	
						77 Fed.	77 Cal.
0.41 HC, 3.4 CO, 2.0 NOx	M A	0.30 0.31	3.26 3.62	1.28 1.44	22.8 20.9	28 24	22 22
0.41 HC, 3.4 CO, 1.0 NOx	M A	0.32 0.26	3.20 4.00	0.91 0.96	22.6 20.4	28 24	22 22

* Certification results from comparable vehicles.

7.3.6.3. Durability Testing

Fuji did not report any durability testing information.

7.3.6.4. Progress and Problems

Fuji has extracted a great deal out of their heat conservation approach. This type of system, however, may be approaching its practical limit at the 0.41 HC, 3.4 CO, 1.0 NOx level, unless more NOx control can be achieved from the basic engine. Fuji's system, in conjunction with a twin-plug cylinder head, like that reported by Nissan, might show promise for emission levels lower than 0.41 HC, 3.4 CO, 1.0 NOx.

7.3.7. Honda

7.3.7.1. Systems Under Development

Honda Motor Company reported no information on systems other than their Compound Vortex Combustion Chamber (CVCC) engine system. A schematic of the CVCC engine can be seen in Figure Honda-1. Honda states emphatically that "...we (Honda) are not convinced to adapt catalysts on the CVCC system vehicle."* Therefore, there will be no discussion of Honda's attempts to work with 3-way, oxidation, or reduction catalysts.

7.3.7.2. Systems to be Used at Various Emission Levels

1.5 HC, 15 CO, 2.0 NOx

Honda stated that for model year 1978 they will be targeting for emission levels of 1.5 HC, 15 CO, and 2.0 NOx for their 49-state cars, and 0.41 HC, 9 CO, and 1.5 NOx for their California vehicles. Both the 49-state and California vehicles will be refinements of Honda's 1977 model year offerings. For the 49-state vehicles (the 1.5 litre Civic CVCC and the 1.6 litre CVCC Accord) Honda will improve the fuel metering and distribution system, adopt the double wall exhaust port liners from their 1977 California vehicles, and incorporate a new evaporative emission control system. Honda will still market vehicles using the 1.2 litre conventional engine and air injection in the 49-states. They are expecting some engine performance improvements, but provided no details on how this will be obtained. Honda anticipates that the 1978 emission levels and fuel economy of the CVCC will be similar to their 1977, 49-state CVCC vehicles. The same is true for their vehicles with conventional engines and air injection although they expect a fuel economy increase in 1978 for this engine. The 1977 fuel economy and emission levels of Honda

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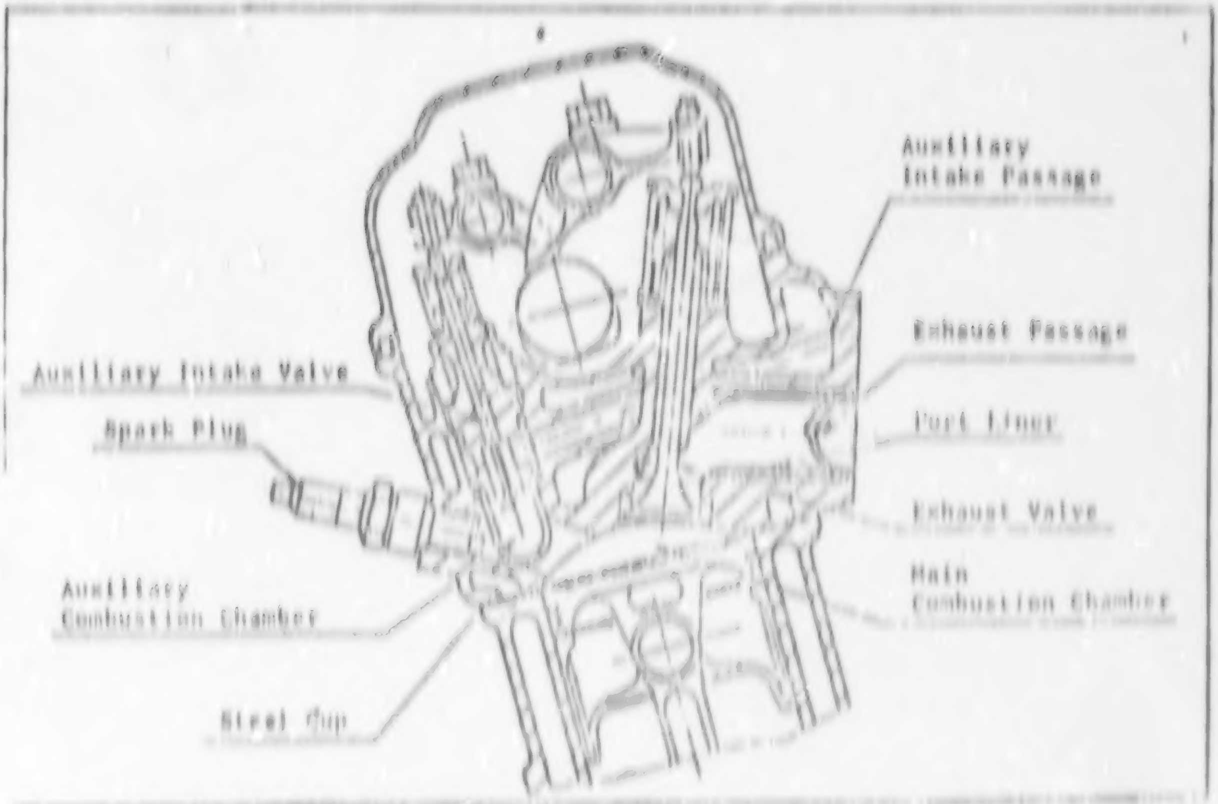
* Honda Motor Company, Status Report Honda's Emission Control Systems, December 15, 1976, page 15.

Figure Honda-1

Reproduced from best available copy.


Auxiliary Intake Passage
Exhaust Passage
Auxiliary Intake Valve
Port Liner
Spark Plug
Exhaust Valve
Main Combustion Chamber
Auxiliary Combustion Chamber
Steel Cup

vehicles can be found in Table Honda-1. Honda stated the cost increase for 1978 would be 15 to 20 dollars due to new evaporative emission controls needed on the CVCC engines.

Table Honda-1

1977 Federal Certification Results

Vehicle	Trans	'75 FTP Exhaust Emissions HC	CO	NOx	Fuel Economy MPG_u	MPG_h
Civic CVCC	4M	1.4	6.3	1.5	39	50
Sedan, 1.5 litre	5M	1.4	6.2	1.4	41	54
	2A	0.9	3.8	1.7	32	37
Civic CVCC	4M	0.9	6.6	1.8	30	41
Wagon, 1.5 litre	2A	0.4	4.6	1.5	27	32
Accord CVCC	5M	1.3	5.2	1.4	38	48
1.6 litre	2A	0.5	4.5	1.7	26	31
Civic, Conventional	4M	0.8	11.2	1.4	28	43
Engine, 1.2 litre	2A	0.6	8.1	1.7	23	29

0.41 HC, 9 CO, 1.5 NOx

Honda foresees that their present 1977 California system will meet these levels as they do presently. Both the 1.5 litre and 1.6 litre CVCC engines will be offered in California with improvements identical to the 49-state vehicles. Honda predicts that there will be no trouble meeting these levels and the vehicles will have an improved driveability and engine performance over comparable 1977 models. Again the cost increases will be due to evaporative emission controls. The 1977 certification data for California vehicles are given in Table Honda-2.

Table Honda-2

		Exhaust Emissions(gm/mi)			Fuel Economy	
Vehicle	Trans	HC	CO	NOx	MPG_u	MPG_h
Civic CVCC	4M	0.29	2.6	1.3	35	46
Sedan, 1.5 litre	5M	0.30	2.8	1.2	36	51
	2A	0.27	3.2	1.4	28	36
Civic CVCC	4M	0.25	3.1	1.2	28	37
Wagon, 1.5 litre	2A	0.27	4.1	1.3	25	32
Accord CVCC,	5M	0.28	2.4	1.2	33	47
1.6 litre	2A	0.21	3.2	1.3	25	32

0.41 HC, 3.4 CO, 2.0 NOx

Honda expects that they would use the system described above at these levels.

0.41 HC, 3.4 CO, 1.0 NOx

To comply with these standards, Honda would use basically the same system as the 0.41 HC, 9.0 CO, 1.5 NOx system with recalibration of the carburetion and optimization of the auxiliary combustion chamber configuration. No EGR or oxidation catalyst is considered necessary by Honda to obtain these levels. Prototype vehicles at 2000 lb IW with 4 speed manual transmission have obtained 0.32 HC, 2.9-3.1 CO, 0.9 NOx with 31-32 MPG_u.

0.41 HC, 3.4 CO, 0.4 NOx

Honda has continued their low NOx study on the CVCC that has been reported the past two years. Work has apparently been stopped on the 2.0 litre engine in favor of assessing low NOx levels and basic understanding of the CVCC process on the 1.5 litre engine. Honda remains convinced these levels are attainable without the use of catalysts on the CVCC system. Basic research has resulted in improved combustion chamber configurations and carburetion which were reflected in the new engine results presented. The 1.5 litre engine is in a 2000 lb IW vehicle with a four speed transmission and achieves 0.3 HC, 3.0 CO, 0.3 to 0.4 NOx. Urban fuel economy is 25 to 26 MPG_U. Fuel economy and drivability is said to have improved over the past year. Work also continues to improve the fuel economy of this engine.

7.3.7.3. Durability Testing Programs

Again, Honda failed to supply durability test data on their proposed emission control system. However, in 1977 certification durability testing, the Honda CVCC system exhibited deterioration factors of less than 1.0. No durability problems for the CVCC system are expected at any of the emission levels considered.

7.3.7.4. Problems and Progress

Honda continues to display leadership in the development of 3 valve, carbureted, pre-chamber, stratified charge engines. However, their reliance on the thermal reactor approach for aftertreatment may require significantly improved thermal reactor efficiency in order to meet future stringent emission standards with good fuel economy.

The work reported to date has shown the ability to meet any of the proposed emissions levels but at a substantial fuel economy penalty at statutory emission levels over the present CVCC vehicles. Honda's aggressiveness to meet the 0.4 NOx goal is hard to ascertain, given the lack of development and durability test details. It appears that Honda's biggest development task is one of improving fuel economy at low emission levels, rather than just attaining those levels. Honda reported their ability to meet the 0.41 HC, 3.4 CO, 0.4 NOx levels as early as 1973. In the four years since then, Honda has not reported much in the way of their development progress to EPA. Honda results with their current aftertreatment show a definite HC/fuel economy relationship. In order to maintain their good fuel economy performance, it is expected that Honda might have to explore sophisticated EGR and/or improved thermal reactors and/or catalytic control.

7.3.8. Mitsubishi

7.3.8.1. Systems Under Development

Oxidation Catalysts

Oxidation catalyst systems currently under development at Mitsubishi are combined with their MCA-JET system described below. Samples of candidate pelleted and monolithic oxidation catalysts are screened and durability tested for attrition resistance and conversion efficiency deterioration before being selected for vehicle durability tests. No test data were presented. It is of some interest that last year's status report included testing of monolith catalysts but apparently no vehicle testing of monolithic catalysts is currently in progress at Mitsubishi.

3-Way Catalysts

Mitsubishi has tested 3-way catalyst systems but has not achieved what they feel are satisfactory results. No test data were presented.

Dual Catalysts

Two vehicles equipped with reduction plus oxidation catalysts are being developed and are undergoing testing at Mitsubishi. This is virtually the same system reported in last year's status report. The engine is based on their current 97.5 CID, 4-cylinder engine with modifications made to the compression ratio, combustion chamber shape, valve timing, bore, stroke, and spark plug location. Detailed descriptions of these modifications were not provided. Except for an improved fuel metering system which maintains the air-fuel ratio at a point slightly richer than stoichiometry, and a new dual-cam choke system (described below), the intake system is basically unchanged from the 1977 system. The EGR system also remains substantially unchanged except for increased flow rates. Two types of air injection techniques are used depending on the NOx catalyst type and location. In one vehicle a reducing catalyst containing ruthenium is located in the exhaust manifold with air injected downstream just ahead of the oxidation catalyst. This NOx catalyst location is being examined for light-off/durability trade-offs with an alternate underfloor location. No air is injected ahead of the ruthenium catalyst because of its poor durability in an oxidizing environment. With another NOx catalyst (substantially base metal plus a small quantity of noble metal) located underfloor just ahead of the oxidation catalyst, an air switching mechanism directs air to the exhaust ports and uses the NOx catalyst as an oxidation catalyst during cold start operation. During hot operation the air is diverted to a point between the catalysts. NOx is then reduced in the first catalyst and the HC and CO combine with oxygen and are oxidized in the second catalyst. In an effort to reduce ammonia formation in the NOx catalyst, Mitsubishi is developing a method to bleed some of this air through a nozzle into the exhaust just ahead of the NOx catalyst. This is done to maintain a CO to O_2 ratio of around 2:1 at which Mitsubishi indicated that ammonia formation is minimized. They are still encountering some difficulty with this split air system in effectively controlling the amount of air metered to the NOx catalyst. (Further description of these vehicles can be found in the section discussing Mitsubishi's system to be used at 0.41 HC, 3.4 CO, 0.4 NOx.)

Other Development Efforts

A dual-cam automatic choke system has been devised by Mitsubishi. This system has a starter cam and a warm-up cam in place of the fast-idle cam in a conventional automatic choke system. The starter cam provides a wider throttle opening during cold start. A coolant temperature sensing wax-element controls the warm-up cam which in turn controls the throttle opening during warm-up. As coolant temperature increases the throttle is gradually closed providing a smooth reduction in engine speed until the engine is thoroughly warmed-up. Mitsubishi claims improved cold start emissions with this system and prevention of catalyst overheating during prolonged engine idling.

A system to control the switching and modulation of secondary air has also been developed by Mitsubishi. During cold start air is injected into the exhaust ports. As coolant temperature increases above 131°F, the air is gradually diverted to a point just ahead of the oxidation catalyst and is modulated with an air control valve by sensing manifold vacuum and air pump discharge pressure. When catalyst(s) temperature becomes excessively high, a relief valve opens discharging the air to the atmosphere away from the catalyst(s).

Port liner development and other heat conservation programs have been suspended at Mitsubishi. Current efforts are being focused on their new lean burning MCA-JET system. When used with an oxidation catalyst, Mitsubishi indicated that this system does not require high exhaust temperatures as do current 1977 models without the MCA-JET. The need for heat conservation techniques to be used with the MCA-JET system to meet statutory emission levels was not addressed by Mitsubishi.

Electronic fuel metering development has been slowed because Mitsubishi indicated EFI has a cost to benefit ratio which is too high. They are continuing to use EFI as a research tool. Similarly, they have no plans to use electronic spark advance control systems from a cost/benefit point of view. Electronic ignition systems remain limited to Mitsubishi's luxury models which are sold in Japan.

Other Systems

Mitsubishi has recently developed a new emission control system called the MCA-JET. It was originally designed to meet 1978 Japanese emission standards but will probably be used to meet U.S. standards as well. Compared to conventional engines with a single intake valve per cylinder, this new system using two intake valves has revealed much improved fuel economy on an equivalent emissions basis. The MCA-JET is pictured in figure Mitsubishi-1. This system is reported to have enhanced acceptance of leaner air-fuel ratios and greater EGR rates. To keep driveability at an acceptable level, further refinements in EGR control may be required.

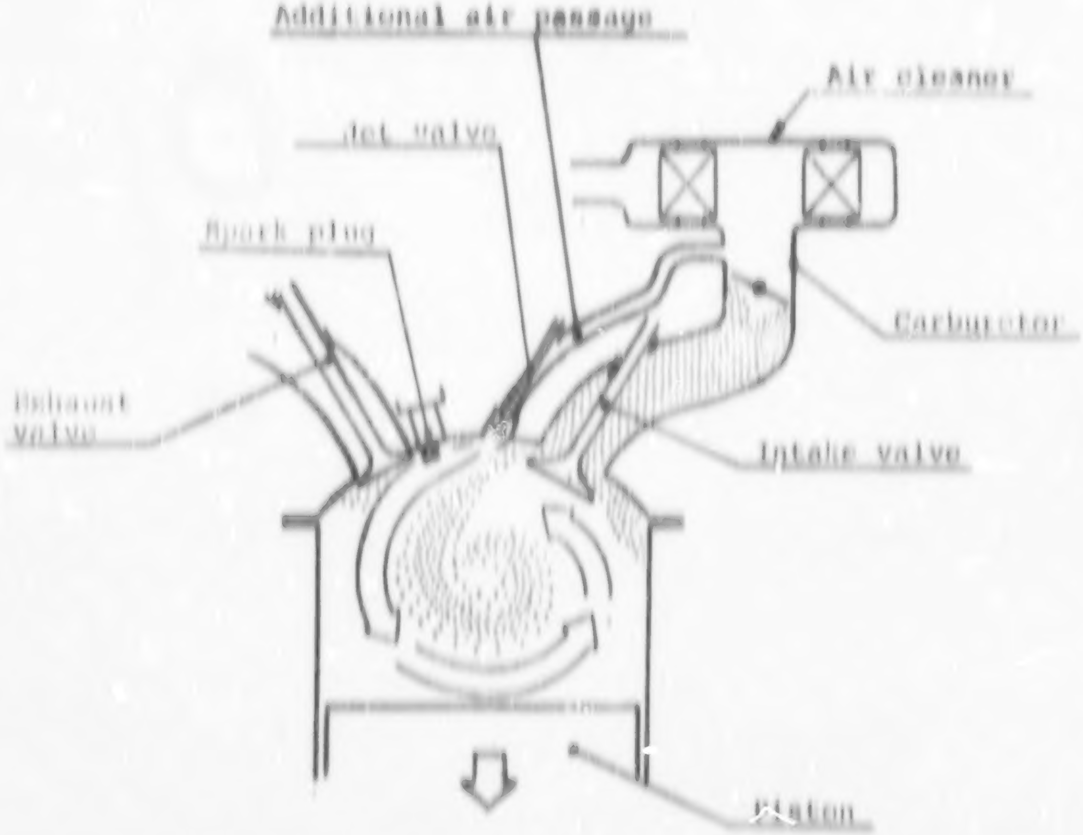

Additional air passage
Air cleaner
Jet valve
Spark plug
Carburetor
Exhaust valve
Intake valve
Piston

Figure Mitsubishi-1
Mitsubishi's New MCA-JET System

The smaller Jet valve is operated simultaneously with the conventional intake valve by a common rocker arm. Air enters the passage above the throttle at approximately atmospheric pressure and passes through the Jet valve into the cylinder. Increased swirl induced by this stream of air improves combustion by increasing flame speed and thus provides the potential for reduced emissions, according to Mitsubishi. At low throttle openings the swirl is greater because of the greater pressure differential across the Jet valve. Better fuel economy has been noted especially under these low load/low speed conditions. As the throttle opening increases, the amount of air inducted through the Jet valve is reduced. To compensate for this, the mixture supplied through the conventional intake valve apparently becomes correspondingly leaner. Under high load conditions, the combustion process is usually good enough without the additional swirl. Mitsubishi notes an extension of the lean limit and increased EGR tolerance with this system. They are currently studying the fuel flow characteristics to obtain better trade-off between emissions, driveability, and fuel economy. No FTP emission data were presented (only 10-mode Japanese data with steady state fuel economy at 37.3 mph of about 45 to 49 MPG using an oxidation catalyst plus EGR.)

Limited information comparing the 1978 MCA-JET system's first cost and operating costs to that of the 1977 conventional engine was presented by Mitsubishi and is shown in Table Mitsubishi-1. The only apparent difference in costs is in the fuel economy benefits which will appear to yield a significant savings of about $140 to the consumer during 50,000 miles of operation. The only increase in cost may come from catalyst replacement at some point after 50,000 miles of operation.

Table Mitsubishi-1

Mitsubishi's 1978 Federal and Calif MCA-JET Models vs. 1977 Federal and Calif Models

	Federal	Calif
First Cost:	Additional cost of Jet valve mechanism approximately offset by elimination of secondary air system (detailed cost data not reported).	Not reported (same as Federal configuration except for slight cost increase due to increased catalyst volume).
Operating Costs:	Fuel - \$140 savings (based on 50,000 miles operation, \$0.65 per gal., and 32.5 MPG_c for 1978 model versus 28.5 MPG_c for 1977 model).	Fuel - \$270 savings (based on 50,000 miles operation, \$0.65 per gal., and 30.0 MPG_c for 1978 model versus 24.0 MPG_c for 1977 model).
	Lubricant - no expected change	Lubricant - no expected change
	Maintenance - no expected change	Maintenance - no expected change
	Catalyst replacement - catalyst: \$10 container: 5 gaskets: 1 labor: 21 (1.5 hr at \$14/hr) \$37	Catalyst replacement - catalyst: \$20 container: 8 gaskets: 1 labor: 21 (1.5 hr at \$14/hr) \$50

Before the MCA-JET system was developed, three other systems were candidates to meet the 1978 Japanese emission standards but further development of these systems has apparently been suspended.

The first of these systems is a lean/rich thermal reactor system with air injection and EGR. This is shown in Figure Mitsubishi-2. The center two cylinders receive a rich mixture (about 13:1 at 25 mph) from one barrel of the carburetor while the outer two cylinders are fed a separate lean mixture (about 17:1 at 25 mph) from the other barrel of the carburetor. This was done principally to reduce NOx formation. Air injection was required primarily to treat CO and HC during transient operation. No FTP emission data are available. Japanese 10-mode emission data were presented with steady state fuel economy at 60 km/hr (37.3 mph) ranging from about 35 to 38 MPG in a 2,200 lb IW vehicle.

The second system is a rich thermal reactor with air injection plus EGR. NOx formation is reduced by rich operation and further reduced by EGR while HC and CO emissions were oxidized in the thermal reactor with the aid of port liners and air injection. Again, no FTP data are available, but Japanese 10-mode data were presented with steady state, 60 km/hr (37.3 mph) fuel economy of about 30 MPG.

The third system is a dual catalyst system substantially the same as that described above in the Dual Catalyst section. No FTP data were presented, but again 10-mode Japanese data with steady state fuel economy at 60 km/hr (37.3 mph) ranging between about 38 and 42 MPG.

7.3.8.2. Systems to be Used at Various Emission Levels

1.5 HC, 15 CO, 2.0 NOx

Mitsubishi's systems to meet this emission level are described in Table Mitsubishi-2. One of the engines reported, the 97.5 CID 4-cylinder, uses the new MCA-JET system with EGR plus an oxidation catalyst located in the exhaust manifold. The other engine is a 121.75 CID 4-cylinder

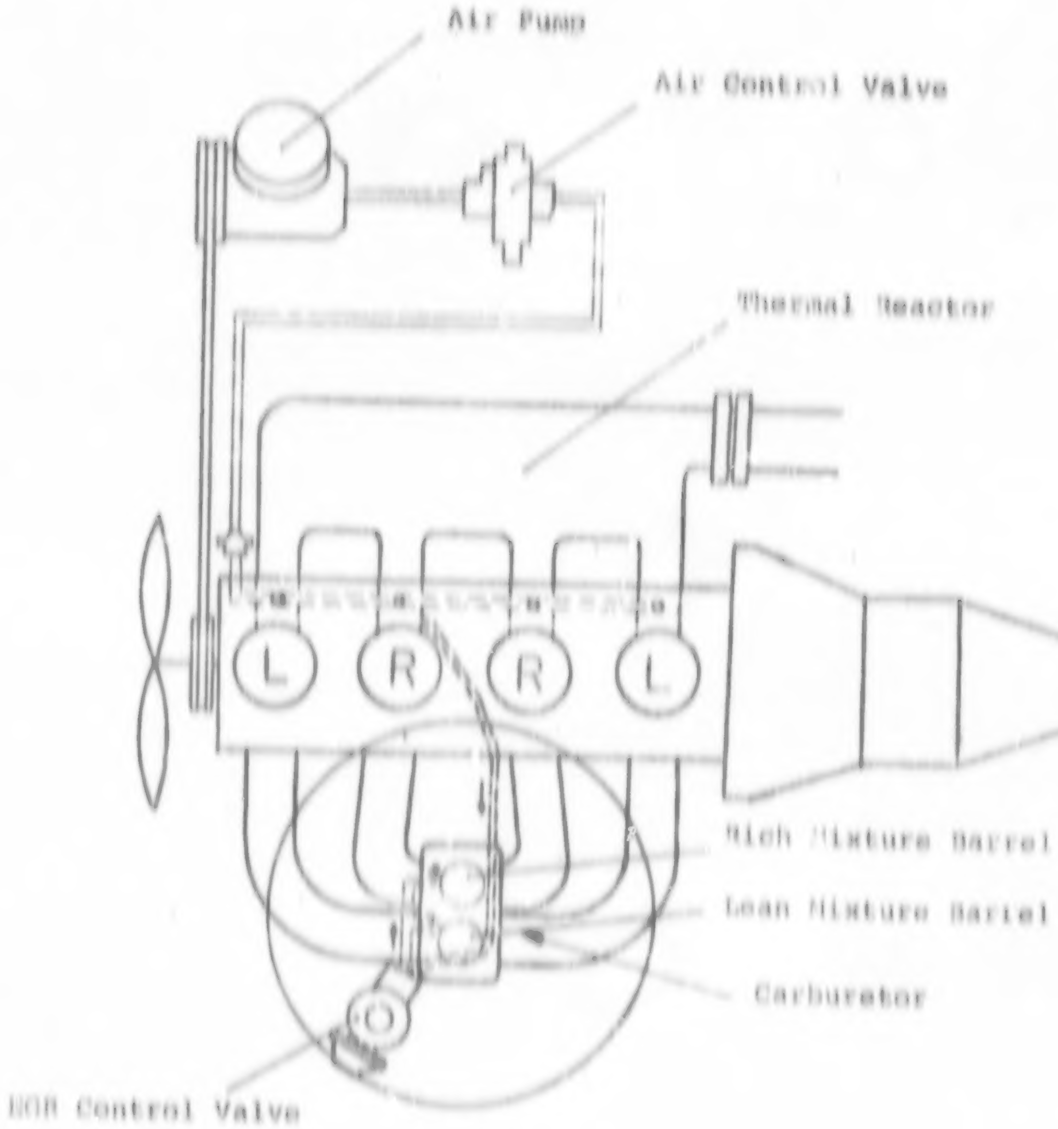

Air Pump
Air Control Valve
Thermal Reactor
L
R
R
L
Rich Mixture Barrel
Lean Mixture Barrel
Carburetor
EGR Control Valve

Figure Mitsubishi-2

Schematic Drawing of Lean/Rich Thermal Reactor System

Table Mitsubishi-2

Emission Control System - 1978: 1.5 HC, 15 CO, 2.0 NOx

	System A	System B
Engine	121.75 CID, 4-cylinder, cast iron block, alum. head	97.5 CID, 4-cylinder, cast iron block, alum. head, MCA-JET
Induction System	staged 2-V carb, auto choke alum. int man exh heated air bi-metal control valve	staged 2-V carb, modified mixture control, auto choke, exh heated air bi-metal control valve
Exh Manifold	4-port, cast iron	4-port, cast iron with radial flow ox cat located in exh man
Ignition System	breaker point, mech and vac adv	breaker point, mech and vac adv
EGR System	spk port vac, int man modulated, coolant temp sensing control valve	spk port vac, int man modulated, coolant temp sensing control valve
Air Injection	reed valve air induction	none
Catalyst	none	pellet, oxidizing, γ-alumina substrate, 0.8 gm Pd, 56,833 sq ft total surface area, location: exh man mfr: Cataler Co., Ltd.
Evap System	charcoal storage, 41.4 cu in, purge thru control valve by int man vac	charcoal storage, 41.4 cu in, purge thru control valve by int man vac

with EGR and reed valve air injection into the exhaust ports with possible further refinement of EGR flow rates, spark advance, and/or other control parameters. Mitsubishi plans to seek certification at these emission levels for the 1978 model year.

0.41 HC, 9 CO, 1.5 NOx

The two engine-systems to meet this level are described in Table Mitsubishi-3. These systems are substantially the same as described in Table Mitsubishi-2 except: System C uses a thermal reactor, increased spark retard and decreased EGR flow compared to System A; and, System D uses increased spark retard, increased EGR flow, and a catalyst with approximately double the surface area and noble metal loading as compared with System B.

0.41 HC, 3.4 CO, 2.0 NOx

These levels are planned to be met for the 1979 and 1980 model years using systems similar to system B, the MCA-JET, in Table Mitsubishi-2. Detailed information as to the exact nature of the planned systems was not presented other than some refinement in carburetion will be necessary as will an increase in catalyst volume.

0.41 HC, 3.4 CO, 1.0 NOx

The MCA-JET system is Mitsubishi's candidate to meet these emission levels for the 1981 model year. Again, detailed information about this system was not presented, but it will be substantially the same as that planned for the 1979-80 model years. They mentioned that increased EGR rates may be necessary to meet the lower NOx level and further refinement of EGR control may be required to keep driveability at an acceptable level.

Table Mitsubishi-3

Emission Control Systems - 1976: 0.41 HC, 9 CO, 1.5 NOx

	System C	System D
Engine	121.75 CID, 4-cyl, cast iron block, alum head	97.5 CID, 4-cyl, cast iron block, alum head, MCA-JET
Induction System	staged 2-V carb, auto choke alum int man, exh heated air bi-metal control	staged 2-V carb, modified mixture control, auto choke, exh heated air bi-metal control valve
Exh Manifold	none	4-port, cast iron with radial flow ox cat located in exh man
Ignition System	breaker point, mech adv and vac adv with dual-diaphragm (decreased flow vs. System A)	breaker point, mech adv and vac adv (increased retard vs. System B)
EGR System	spk port vac, int man modulated, coolant temp sensing control valve (decreased flow vs. System A)	spk port vac, int man modulated, coolant temp sensing control valve (increased flow vs. System B)
Air Injection	reed valve air induction	none
Thermal Reactor	yes	none
Catalyst	none	pellet, oxidizing, γ-alumina substrate, 1.6 gm pd, 111,000 sq. ft. total surface area, location: exh man mfr: Cataler Co, Ltd.
Evap System	charcoal storage, 41.4 cu in., purge thru control valve by int man	charcoal storage, 41.4 cu in., purge thru control valve by int man

0.41 HC, 3.4 CO, 0.4 NOx

A dual catalyst system is continuing to be developed by Mitsubishi to meet statutory emission standards. This is substantially the same system previously discussed in the Dual Catalyst section. Durability emission data are presented in the Durability Testing section below. Low mileage emission results look promising with vehicle number 206 (NOx catalyst located underfloor), however, testing was suspended at 20,000 miles of durability testing due to an increase in emissions in excess of statutory levels. The second vehicle, number 502 (NOx catalyst located in the exhaust manifold), is continuing to be tested at 21,250 miles even though emissions are exceeding those of the first vehicle. Spark retardation is being considered by Mitsubishi as a means to reduce engine out HC, CO, and NOx levels and also to get better light-off of the catalysts. A modified EGR valve is being adopted in an effort to reduce the need for retarded spark and the associated fuel economy penalty.

The MCA-JET system is also a prospective candidate to meet statutory emission levels primarily because of its ability to accept leaner air-fuel ratios and increased EGR rates. Mitsubishi feels further refinements over conventional EGR may be required to further reduce NOx and maintain acceptable driveability. No specific development effort to achieve statutory levels with the MCA-JET system was reported. This system is being developed, however, to meet future 1978 model year Japanese standards.

7.3.8.3. Durability Testing

The two dual catalyst vehicles described above and an MCA-JET vehicle represent the only durability data reported. These are presented in Table Mitsubishi-4. No other durability data were presented although

Table Mitsubishi-4

Dual Catalyst and MCA-JET Durability Data

Veh. #	IW	Engine and Drive Train	System	System Mileage	HC	CO	NOx	MPG_U	MPG_H	Comments
206	2750	97.5 CID,	dual cat, split	0	0.24	1.54	0.32	22.9	–	–
		man trans,	secondary air with	600	0.34	1.88	0.35	–	–	–
		1.889 axle	switching and air	5,000	0.45	2.80	0.46	–	–	–
		ratio	control, EGR	10,759	0.56	4.72	0.60	–	–	–
			(NOx cat located	15,000	0.39	3.55	0.63	–	–	–
			underfloor)	20,000	0.49	3.79	0.69	–	–	test run suspended due to increase in emissions
502	2750	97.5 CID,	dual cat	0	0.85	4.40	0.34	24.2	–	–
		man trans	secondary air	8,000	0.79	6.82	0.54	–	–	–
		1.889 axle	control, EGR	15,600	0.85	6.75	0.45	–	–	before maintenance
			(NOx cat located	15,600	0.65	6.43	0.41	–	–	after maintenance
			in exh man)	18,750	0.68	6.07	0.42	–	–	–
				21,250	0.82	6.86	0.61	–	–	before maintenance
				21,250	0.83	6.35	0.59	–	–	after maintenance, testing continuing
509	2750	97.5 CID,	ox. cat	0	0.20	1.60	1.24	26.9	36	
		MCA-JET,	located in exh. man,	4,992	0.28	3.53	0.95	–	–	
		man trans.,	EGR	10,300	0.26	3.83	1.19	–	–	before maintenance
		1.889 axle ratio			0.28	4.36	1.07	–	–	after maintenance
				16,000	0.27	4.12	1.21	–	–	
				22,000	0.30	3.51	1.08	–	–	
				25,000	0.25	3.10	1.22	–	–	before maintenance
					0.28	2.89	1.02	–	–	after maintenance
				30,000	0.36	4.70	0.84	–	–	
				37,000	0.31	5.16	0.76	–	–	before maintenance
					0.28	3.97	0.99	–	–	after maintenance testing continuing

another vehicle using the MCA-JET has just begun testing and Mitsubishi expects to add more vehicles in the future.

7.3.8.4. Problems and Progress

Mitsubishi's recent efforts have been directed toward development of their MCA-JET system to comply with Japan's 1978 emission standards. For the U.S. market, however, substantial development of this system still appears necessary to meet levels of 0.41 HC, 3.4 CO, 1.0 and 2.0 NOx as well as statutory levels. The dual catalyst systems designed to meet statutory emission levels show some promise but durability is a problem. Development efforts directed toward combinations of Mitsubishi's innovative control techniques such as the MCA-JET and the dual-cam choke systems may show good potential. Durability and fuel economy results of the MCA-JET system will be especially interesting. Mitsubishi will have to overcome problems in such areas as precise control of fuel metering, EGR flow, spark advance, and secondary air modulation without the aid of electronic control which they feel is undesirable from a cost/benefit standpoint.

7.3.9. Nissan (Datsun)

7.3.9.1. Systems Under Development

3-Way Catalyst System

The Nissan 3-way catalyst system is shown in Figure Nissan-1. The system uses L-Jetronic electronic fuel injection, an oxygen sensor, backpressure EGR (up to 12%), and a 3-way catalyst. System optimization testing was directed at statutory emission levels and was conducted on a 3000 pound IW vehicle (VIN 8D-740) equipped with a 2.8 litre engine and a manual transmission. The best reported results were 0.27 HC, 1.75 CO, 0.32 NOx, 17.9 MPG_u. The fuel economy of the similar 1977 Federal data vehicle was also 17.9 MPG_u, and the fuel economy of the similar durability vehicle ranged from 17.2 to 18.2 MPG_u.

A number of promising pelleted and monolithic 3-way catalysts were evaluated in laboratory and engine dynamometer testing at Nissan. Some of the better candidates are shown in Figures Nissan-2 through Nissan-5. From Figures Nissan-2 and Nissan-3, it can be seen that the high temperature laboratory aging of 100 hours results in greater catalyst deterioration than the equivalent of 30,000 km on the engine dynamometer. The Z value on the figures is defined as:

$$Z = (O_2 + 0.5\ NO)/(0.5\ CO + 0.5\ H_2 + 1.5\ HC) \text{ where } H_2 = 1/3\ CO.$$

Catalysts JB 1101 and AB 318 are particularly impressive in the laboratory testing. After 100 hours of aging, they were reported to have HC/NOx crossover efficiencies of 96% and 94% respectively.

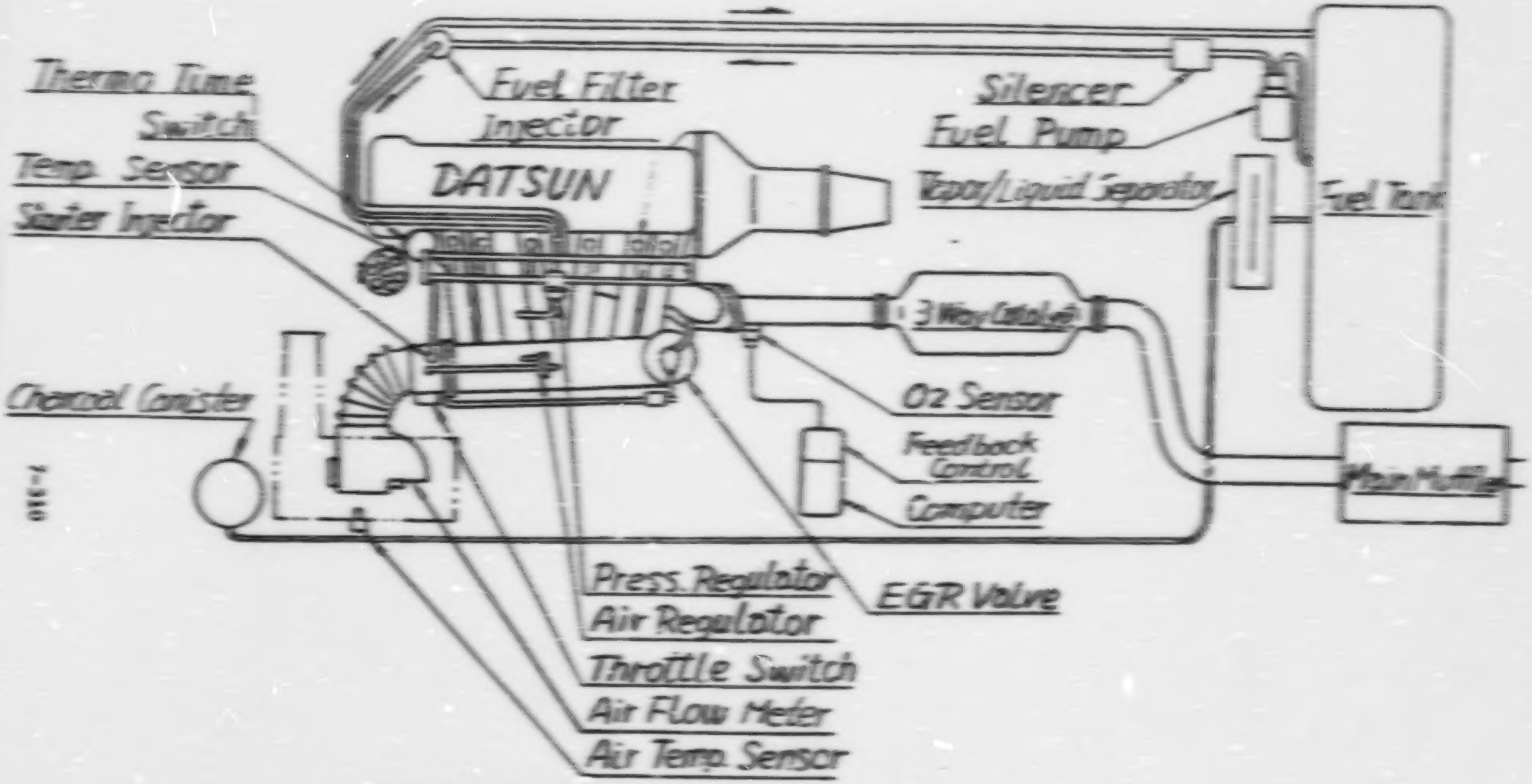
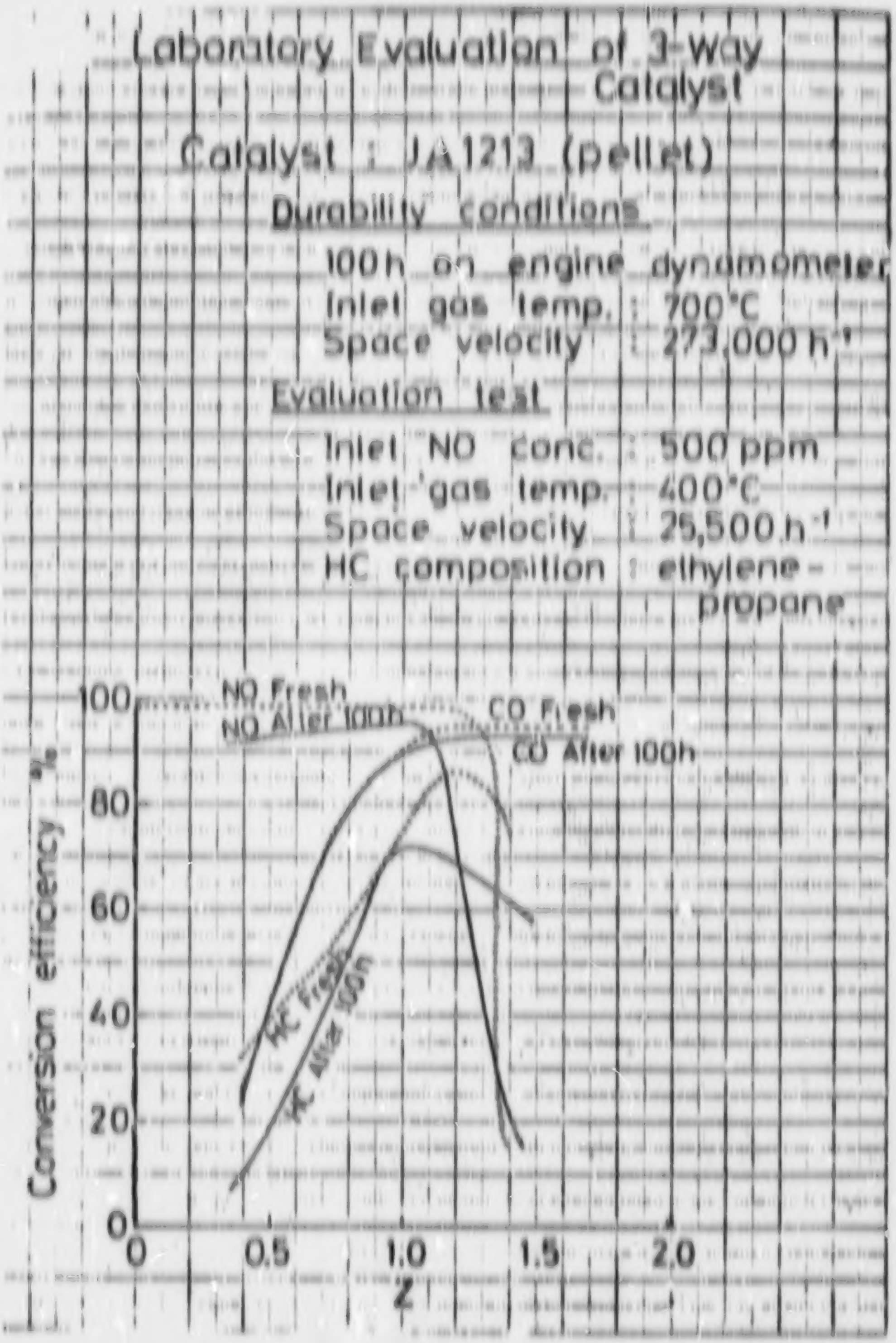

Thermo Time Switch
Temp. Sensor
Starter Injector
Charcoal Canister
Fuel Filter
Injector
DATSUN
Silencer
Fuel Pump
Vapor/Liquid Separator
Fuel Tank
3 Way Catalyst
O2 Sensor
Feedback Control
Computer
Main Muffler
EGR Valve
Press. Regulator
Air Regulator
Throttle Switch
Air Flow Meter
Air Temp. Sensor

Figure Nissan-1*

3WAY CATALYST SYSTEM
WITH ELECTRONIC FUEL INJECTION

* From Nissan Status Report, December 1976, page IV-3

Figure Nissan - 2*



Laboratory Evaluation of 3-Way Catalyst

Catalyst : JA1213 (pellet)

Durability conditions

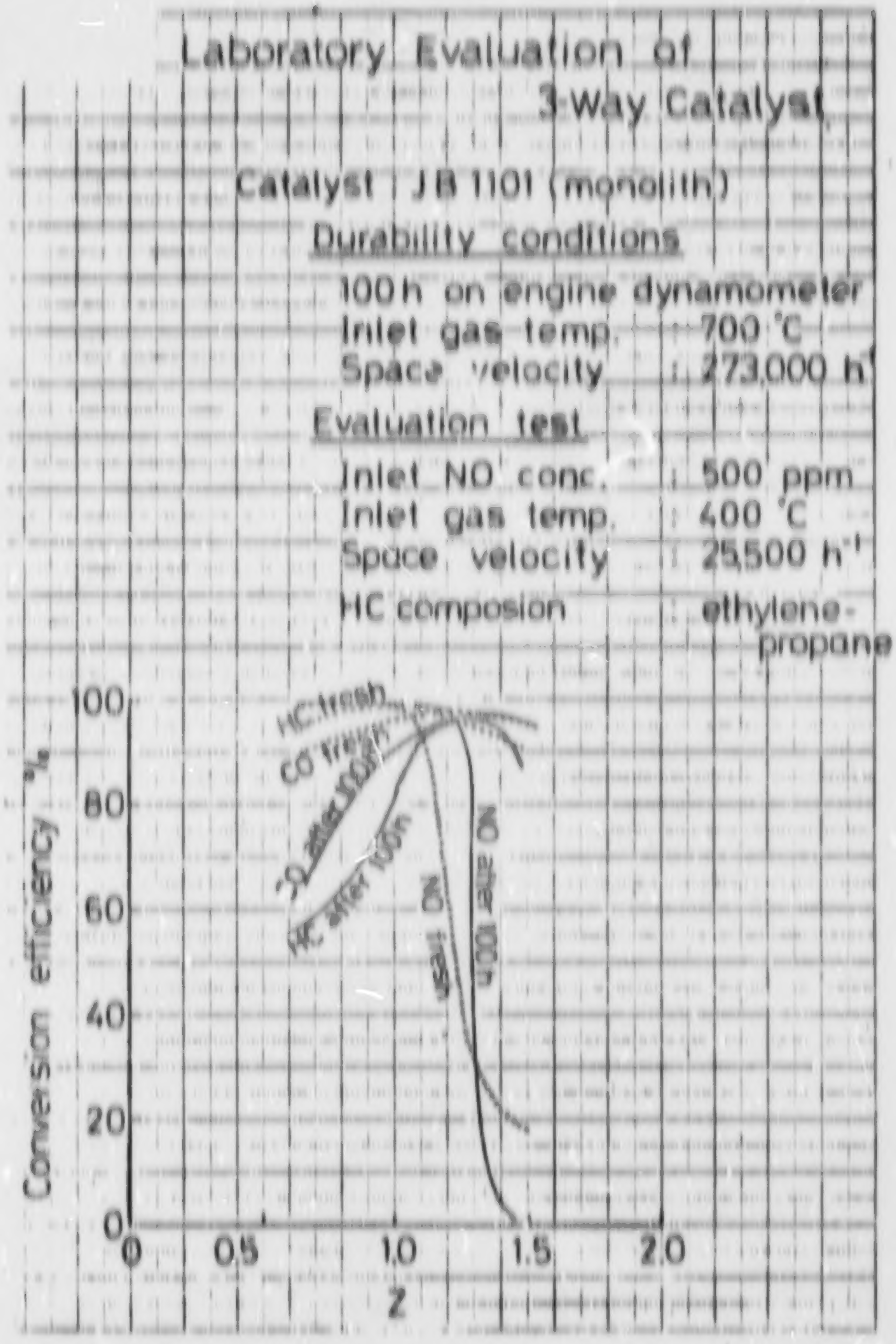
100 h on engine dynamometer
Inlet gas temp. : 700°C
Space velocity : 273,000 h^{-1}

Evaluation test

Inlet NO conc. : 500 ppm
Inlet gas temp. : 400°C
Space velocity : 25,500 h^{-1}
HC composition : ethylene-propane

*from Nissan Status Report, December 1976, page V-14.

Figure Nissan - 38



Laboratory Evaluation of 3-way Catalyst

Catalyst : JB 1101 (monolith)

Durability conditions

100 h on engine dynamometer
Inlet gas temp. : 700 °C
Space velocity : 273,000 h⁻¹

Evaluation test

Inlet NO conc. : 500 ppm
Inlet gas temp. : 400 °C
Space velocity : 25,500 h⁻¹
HC composion : ethylene-propane

* from Nissan Status Report, December 1976, page V-16.

Figure Nissan - 44

Laboratory Evaluation of 3-Way Catalyst

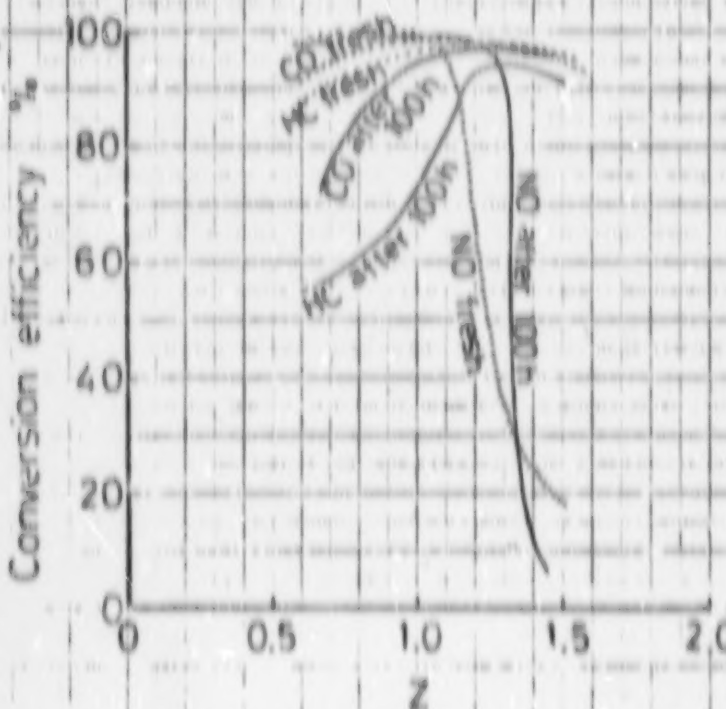
Catalyst : AB 318 (monolith)

Durability conditions

100 h on engine dynamometer
Inlet gas temp. : 700 °C
Space velocity : 273000 h^{-1}

Evaluation test

Inlet NO conc. : 500 ppm
Inlet gas temp. : 400 °C
Space velocity : 25,500 h^{-1}
HC composition : ethylene - propane



* from Nissan Status Report, December, 1976, page V-17.

Figure Nissan - 5*

Engine Dynamometer Evaluation of 3-Way Catalyst

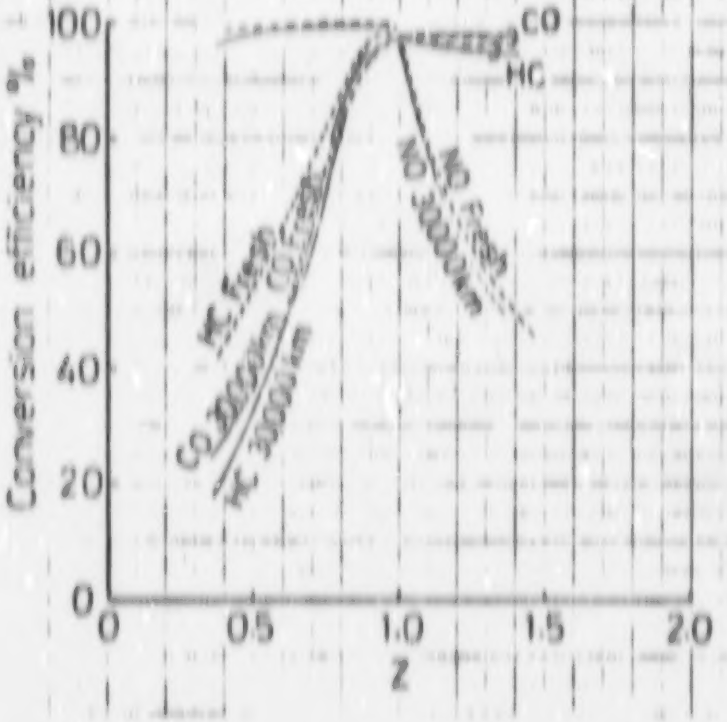
Catalyst : JA 1213 (pellet)

Durability test mode

Proposed Japan MOT mode
on engine dynamometer
Inlet gas temp. : 350~700°C

Evaluation test

Inlet NO conc. : 500 ppm
Inlet gas temp.: 450°C
Space velocity : 27,000 h^{-1}



* From Nissan Status Report, December 1976, page V-20.

Fast Burn System

The Nissan fast burn system, shown in Figure Nissan-6, demonstrates a unique approach toward meeting statutory emission levels without catalytic NOx control. The system utilizes two spark plugs per cylinder which greatly increases the burn rate of the air-fuel charge. Then large amounts of EGR (up to 30%) are added to reduce NOx to statutory levels. The high EGR rates in turn slow down the burn rate, but the desired NOx control is achieved. As shown in Figures Nissan-7 and Nissan-8, the conventional engine does not have the high EGR tolerance (or good fuel consumption) of the fast burn engine. Figure Nissan-9 shows that at the same NOx level, the conventional engine experiences combustion stability problems. High HC emissions are the result of incomplete combustion at the low IMEP levels.

Since only NOx emissions are controlled by combustion in the engine, HC and CO control is being attained with air injection and an oxidation catalyst.

Optimization testing has been done on a 2750 pound IW vehicle with a 2.0 litre engine and a manual transmission (VIN 8D-946). The best reported results are shown in Table Nissan-1. The catalyst was reported to be a 95 cu in., all platinum monolith. The noble metal loading of the catalyst and engine-out emissions were not reported.

Table Nissan-1*

Test Results of the Vehicle Using the Fast Burn System

HC	CO	NOx	MPG_u	MPG_h	MPG_c
0.17	1.85	0.35	21.9	--	--
0.22	2.09	0.38	22.2	33.1	26.1
0.24	2.01	0.37	22.6	33.4	26.4

*from Nissan Status Report, December 1976, Page IV-31.

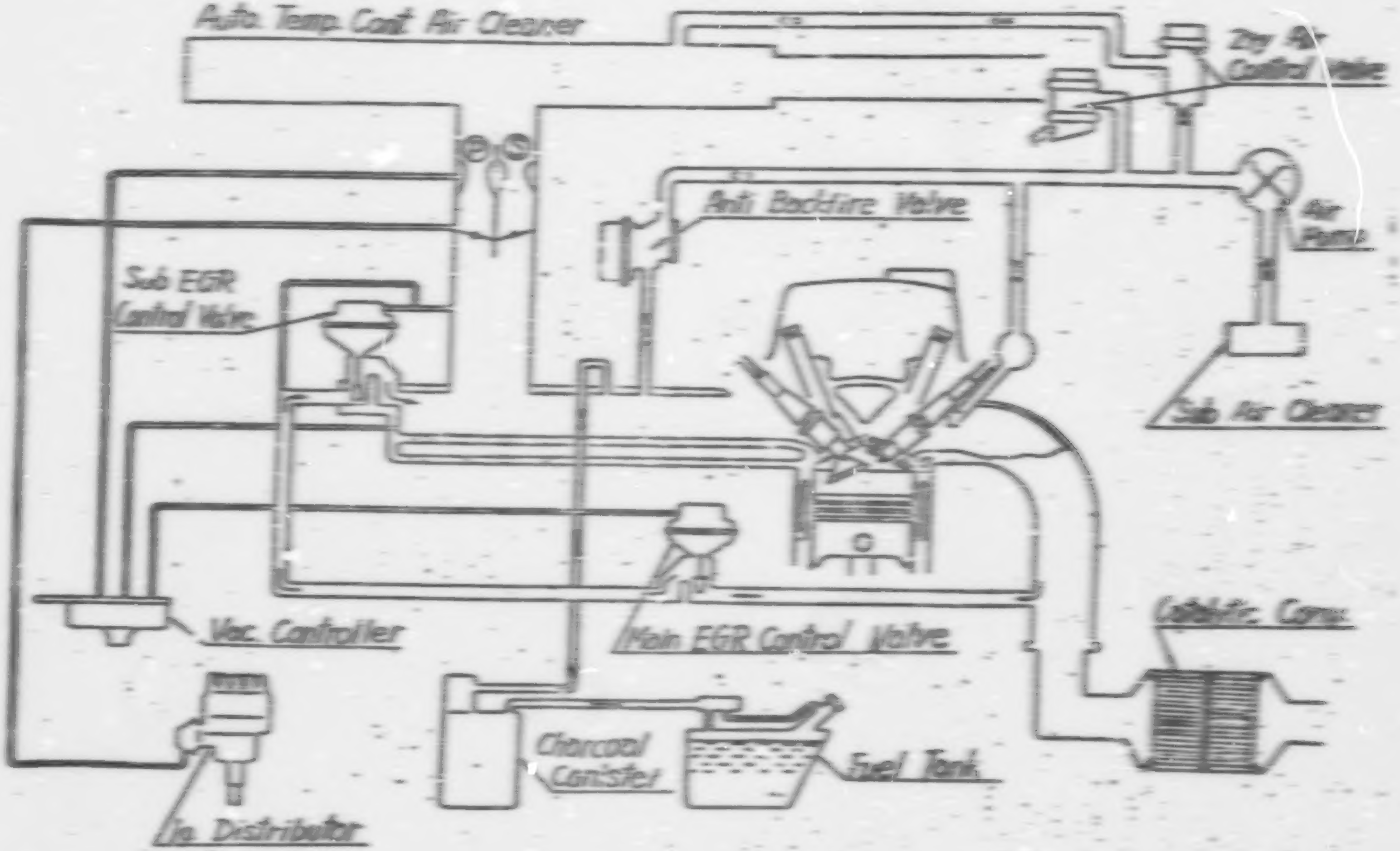

Auto. Temp. Cont. Air Cleaner
2ry Air Control Valve
Air Pump
Anti Backfire Valve
Sub EGR Control Valve
Sub Air Cleaner
Vac. Controller
Main EGR Control Valve
Catalytic Conv.
Charcoal Canister
Fuel Tank
To Distributor

Figure Nissan-6*
NISSAN FAST BURN SYSTEM

* from Nissan Status Report, December 1976, page IV-15.

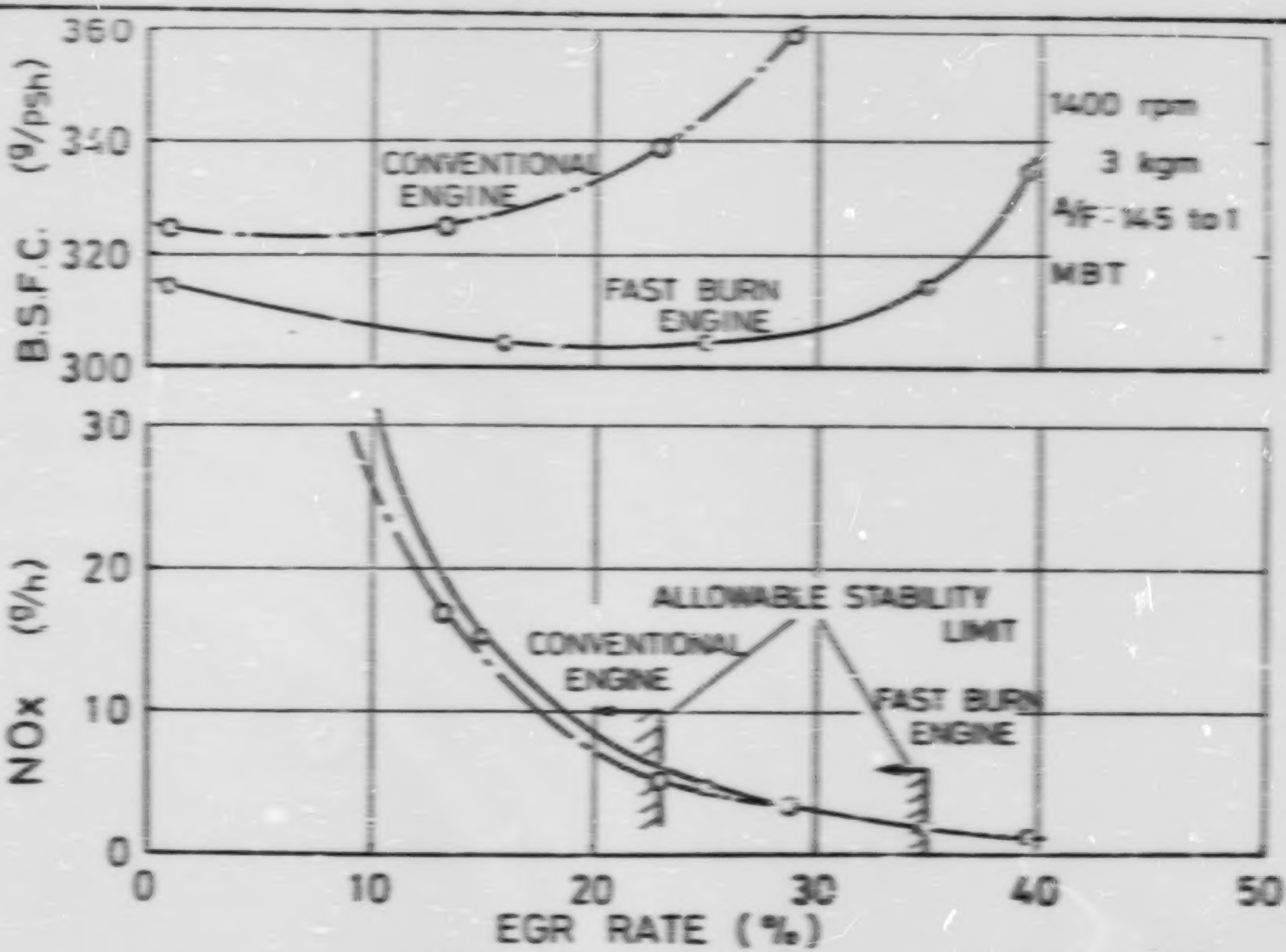


Figure Nissan-7* IMPROVEMENTS OF EGR LIMIT AND B.S.F.C.

* from Nissan Status Report, December 1976, page IV-24

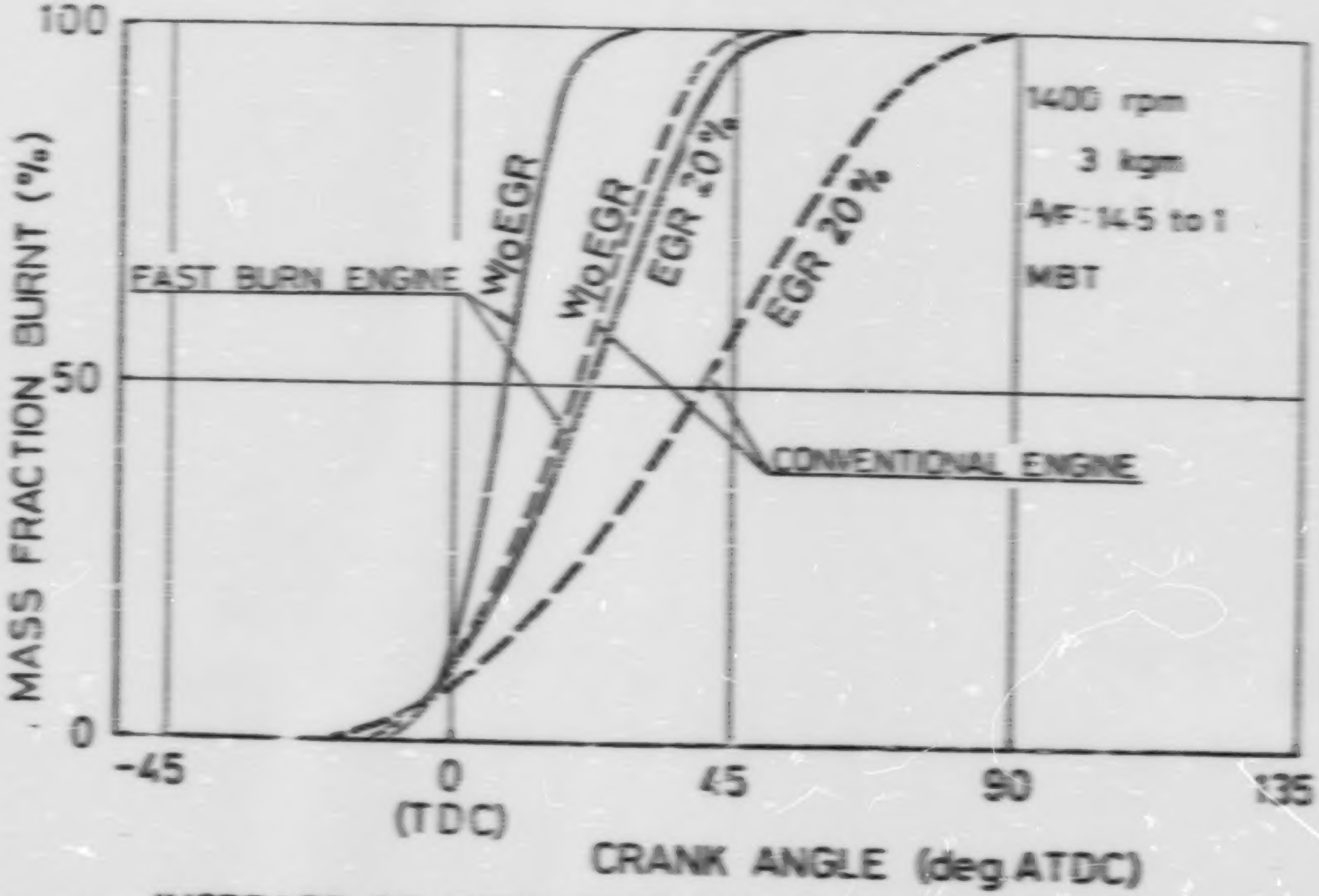


Figure Nissan- 8* INCREASE OF COMBUSTION RATE IN FAST BURN ENGINE

* from Nissan Status Report, December 1976, page II-28

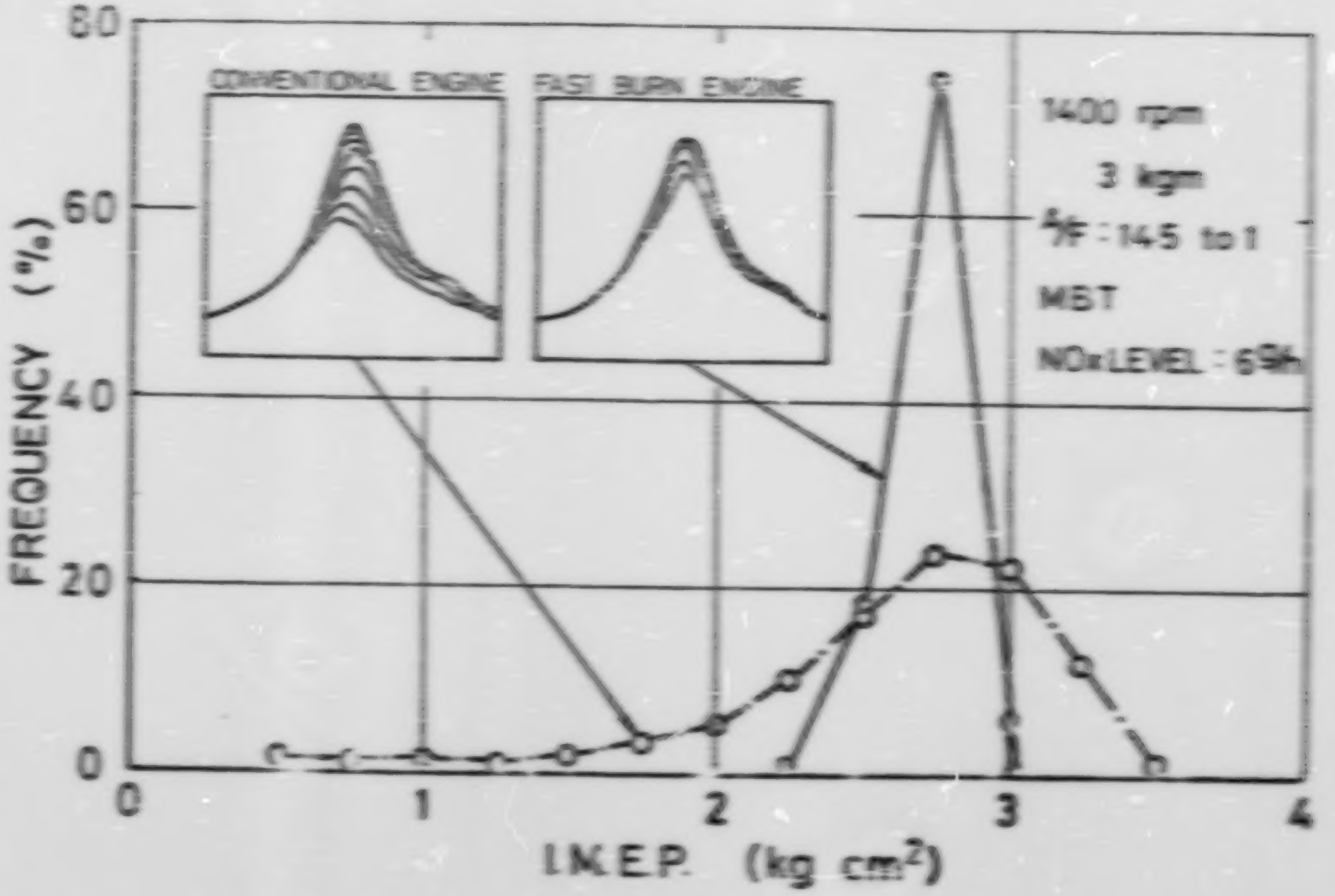


Figure Nissan-9* IMPROVEMENT OF COMBUSTION STABILITY IN FAST BURN ENGINE

* from Nissan Status Report, December 1976, page 23-29

Nissan reported that power output of the fast burn engine is similar to current models, but some loss in driveability has been noted due to the necessity of introducing EGR sooner than desirable after the cold start to achieve the required NOx control. Nearly all vehicle manufacturers delay the introduction of EGR until after the engine has warmed up to retain good cold start driveability.

For the purposes of comparison to Table Nissan-1 the comparable 1977 Federal certification fuel economy vehicle achieved 23.0 MPG_u, 34.1 MPG_h, and 26.9 MPG_c. The urban fuel economy of the comparable 1977 Federal durability vehicle ranged from 21.4 to 22.8 MPG_u. Thus, the fast burn vehicle has virtually equivalent fuel economy while achieving statutory emission levels.

Other Components Under Development

A 3-way catalyst system using a feedback carburetor is now being durability tested at Nissan to determine its ability to comply with the 1978 Japanese emission levels. The carburetor uses feedback control to an air bleed as shown in Figure Nissan-10. One vehicle was reported to have completed 30,000 km. The major problem with the carburetor was said to be durability of the air bleed actuator.

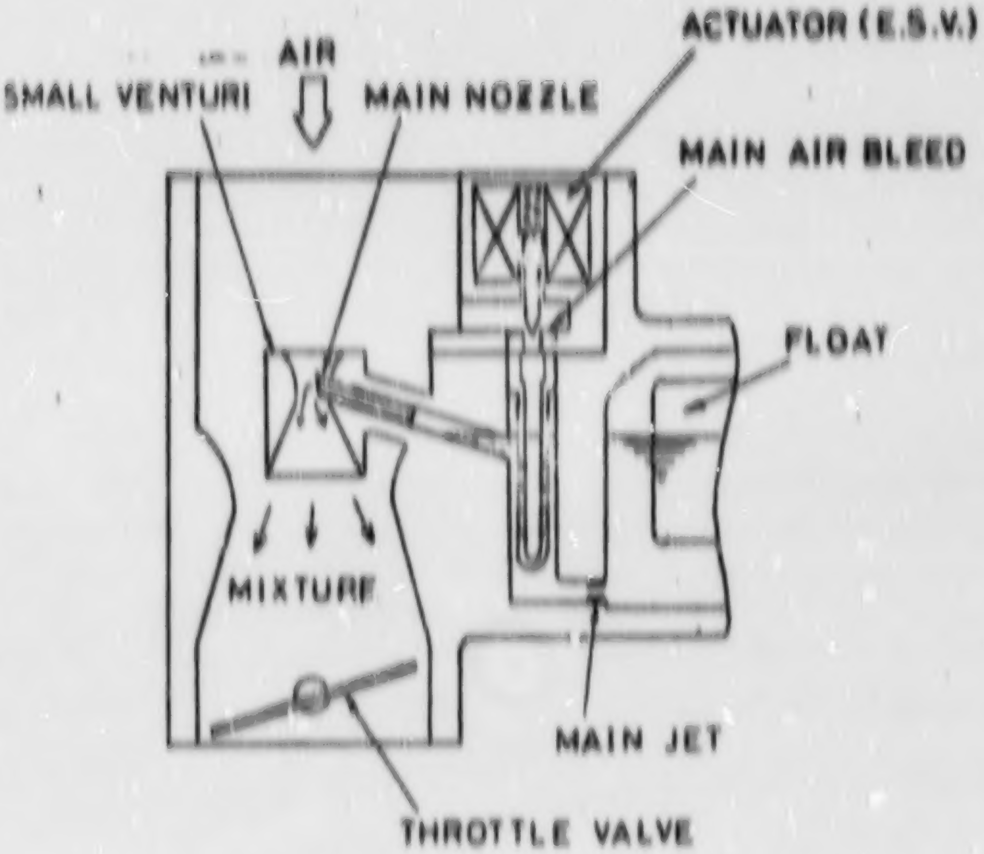
7.3.9.2. Systems to be Used at Various Emission Levels

1.5 HC, 15 CO, 2.0 NOx

If the 1978 emission standards remain at these levels, the emission control system of Nissan will not change greatly from those of 1977. Table Nissan-2 shows the planned systems.

Figure Nissan-10*

Electronically Controlled Carburetor


ACTUATOR (E.S.V.)
AIR
SMALL VENTURI
MAIN NOZZLE
MAIN AIR BLEED
FLOAT
MIXTURE
MAIN JET
THROTTLE VALVE

* from Nissan Status Report, December 1976, page V-4.

Table Nissan-2*

1978 Federal Emission Control Systems

Family	Configuration	CID	IW	Emission Control System
L280F	I-6	168	3000	EFI + EGR
L240F	I-6	146	3000	EFI + EGR
L200F	I-4	119	2750	AIR + EGR
A140F	I-4	85	2250	AIR + EGR
A141F	I-4	85	2250	RAIR** + EGR + OC

* From Nissan Status Report, Dec. 1976, p. I-3
** RAIR = reed valve air induction system

The EFI system on the vehicles with six cylinder engines is the Bosch L-Jetronic system. All EGR systems are backpressure modulated for EGR control which is somewhat proportional to load. A new configuration of the small inline four cylinder engine is planned, which incorporates a system using pulse AIR, EGR, and an oxidation catalyst. Nissan has previously used oxidation catalysts only in California.

Fuel economy of these vehicles will be improved, according to Nissan, due to some vehicle weight reductions and recalibrations. The change in initial cost of these models is expected to range from a $10 reduction to a $40 increase. Increased costs are due to the addition of breakerless ignition and low-maintenance batteries on some models. The reduced costs are for a reduction in cost of the breakerless ignition for vehicles already with breakerless ignition, apparently due to increased volume purchases. Maintenance costs are going to be reduced in 1978 by about $90 to $125 (Nissan stated this as $34 to $50 plus 4 to 5 hours of maintenance time).

0.41 HC, 9 CO, 1.5 NOx

While stating that they could certify vehicles in 1978 on a Federal basis at this emission level, Nissan indicated that there was insufficient lead time remaining to procure an ample supply of oxidation catalysts from their supplier.

The systems planned for California in 1978 are described in Table Nissan-3. High altitude vehicles will be identical to the California vehicles.

Table Nissan-3*
1978 California Emission Control Systems

Family	Configuration	CID	IW	Emission Control System
L28IC	I-6	168	3000	EFI + EGR + Ox. Cat.
L24IC	I-6	146	3000	EFI + EGR + Ox. Cat.
L20IC	I-4	119	2750	AIR + EGR + Ox. Cat.
A14OC	I-4	85	2250/2500	AIR + EGR + Ox. Cat.

* From Nissan Status Report, Dec. 1976, p. I-3.

Initial cost of the 1978 California vehicles is to be reduced by $50 to $70 despite the addition of the low maintenance battery (not really an emission control device), because of cost reductions in other emission components. One example is a reduction in noble metal loading of the catalyst. Maintenance costs will be reduced by an amount similar to that of the Federal vehicles for 1.5 HC, 15 CO, 2.0 NOx.

The difference in initial cost between the currently planned Federal and California systems was said to be $85 to $95.

0.9 HC, 9 CO, 2.0 NOx

Since current Federal vhicles from Nissan generally do not use oxidation catalysts, their emissions would not comply with the 0.9 HC, 9 CO, 2.0 NOx emission levels. The current California vehicles would easily achieve these levels. Emissions of the Federal vehicles are sufficiently close to these levels that Nissan could possibly recalibrate these vehicles and achieve 0.9 HC, 9 CO, 2.0 NOx without catalytic aftertreatment.

0.41 HC, 3.4 CO, 2.0 NOx

Nissan said that they have not yet fully developed systems for this emission level. Their work for California indicates that CO may be their biggest problem. The data to support this contention apparently were developed by installing high mileage catalysts, which had been run about 50,000 miles, on low mileage vehicles. The results of this testing are shown in Table Nissan-4.

Nissan further substantiated their CO problem with evidence that EPA testing generally shows higher CO levels than found at Nissan on the same vehicles. Nissan mentioned that CO control on high altitude vehicles is of even more concern, and considerable lead time would be necessary to resolve the problem.

The Nissan analysis may have been too conservative. The vehicles in Table Nissan-4 were not calibrated for 3.4 CO. Considerable enhancement of the systems is still possible based on the engine-out emissions shown in Table Nissan-4, particularly for the vehicle with the 85 CID engine. Other manufacturers have reported lower engine-out CO emissions at stoichiometric operation than reported here by Nissan. Also the catalysts used by Nissan in this testing, despite their high loading, are not considered to be the best technology available. Apparently Nissan did not test catalysts from their usual supplier on this vehicle. All but one of their 1977 California durability vehicles have already completed 50,000 miles with emission levels below 0.41 HC, 3.4 CO, 1.5 NOx.

Table Nissan-4*

Vehicle Testing for 0.41 HC, 9 CO, 1.5 NOx

VIN	CID	IW	Trans	Emission Control System	Catalyst** [illegible]	Catalyst** [illegible]	With Catalyst HC	With Catalyst CO	With Catalyst NOx	Without Catalyst HC	Without Catalyst CO	Without Catalyst NOx
A-450	85	2250	A	AIR+EGR+OC	X		0.29	2.69	0.82	1.43	21.0	1.01
						X	0.36	2.66	1.24	1.46	19.8	1.23
AB-361	119	2750	M	AIR+EGR+OC	X		0.23	2.69	1.26	1.41	24.2	1.37
						X	0.39	3.22	1.25			
BB-340	146	3000	A	EFI+EGR+OC		X	0.37	2.66	1.17	1.56	22.8	1.18
P-503	168	3500	A	EFI+EGR+OC	X		0.29	3.70	1.08	0.85	20.5	1.29
						X	0.31	4.12	1.26			

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* from Nissan Status Report, December 1976, page II-4

** noble metal loading of 70 gm/cu ft.

0.41 HC, 3.4 CO, 1.0 NOx

A 1.0 NOx development program for 1981 has not yet been conducted by Nissan. They indicated that at 1.0 NOx, their 0.4 NOx systems would probably be used. Those systems are a 3-way catalyst system and their fast burn system. Further efforts on the oxidation catalyst systems could make them feasible for lighter weight vehicles, according to Nissan.

0.41 HC, 3.4 CO, 0.4 NOx

The Nissan 3-way catalyst system and fast burn system are being developed for statutory emission levels. The development status of these systems was discussed under the section entitled Systems Under Development.

The fuel economy of these systems was seen to be equivalent to 1977 Federal Nissan vehicles. Initial costs and maintenance costs of the two systems were not discussed by Nissan.

7.3.9.3 Durability Testing

A single 3-way catalyst vehicle was durability tested at Nissan. The vehicle is the previously described vehicle number 8D-740 (see Systems Under Development). The catalyst was described as a 3 litre, pelleted catalyst which was mounted underfloor. No further catalyst description was given. The durability results are shown in Table Nissan-5. HC and CO control appear to be deteriorating at the 30,000 mile point.

Table Nissan-5

3-Way Catalyst Durability

Mileage	HC	CO	NOx	MPG_M	Comments
0	0.27	1.75	0.32	17.9	
5,000	0.45	3.30	0.42	17.7	
	0.31	3.25	0.38	17.7	After Maintenance
10,000	0.54	2.82	0.43	18.4	
	0.36	2.83	0.43	18.1	After Maintenance
15,000	0.28	2.99	0.41	18.3	
20,000	0.40	2.62	0.47	18.3	
25,000	0.40	3.35	0.37	17.9	
30,000	0.53	4.23	0.41	17.9	

Two oxidation catalyst vehicles were reported to be undergoing durability testing for 0.41 HC, 9 CO, 1.5 NOx. Vehicle BR-342 was a 3000 pound IW vehicle with a 146 CID engine and an automatic transmission. It was equipped with an EFI + EGR + OC system. The catalyst was a monolith of about 100 cu in. with a loading of 40 gm/cu ft. Vehicle F-560 was a 3000 pound IW vehicle with an automatic transmission and a 168 CID engine. It also has an EFI + EGR + OC system. This catalyst was about 100 cu in. with a 25 gm/cu ft. loading. The test results of both vehicles are shown in Table Nissan-6.

Table Nissan-6*

Oxidation Catalyst Durability Vehicles

VIN	Mileage	HC	CO	NOx	MPG_U	Comments
BK-342	0	0.28	3.3	1.43	15.0	
	3,545	0.31	3.4	1.60	14.6	
	4,000	0.31	4.0	1.22	14.4	
	10,171	0.27	3.0	2.01	13.7	
	10,185	0.36	3.7	1.35	14.8	After Maintenance
	12,418	0.33	3.3	1.03	15.1	
	13,191	0.37	2.8	1.09	15.1	
F-560	0	0.29	4.9	1.20	14.5	
	4,000	0.31	3.0	1.46	15.2	
	10,000	0.27	3.9	1.46	15.7	
	12,500	0.39	3.7	1.35	13.4	
	15,000	0.36	3.1	1.05	16.3	
	20,000	0.39	3.1	1.33	15.2	

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* From Nissan Status Report, December 1976, pages II-6 and II-7.

The fuel economy of similar 1977 Federal certification vehicles is shown in Table Nissan-7.

Table Nissan-7

Fuel Economy of 1977 Federal Certification Vehicles Which are comparable to the Oxidation Catalyst Vehicles in Table Nissan-6

		Fuel Economy		
Comparable to	FE or Durability Vehicle	MPG_U	MPG_H	MPG_C
BK-342	FE	17.1-17.5	21.8-24.2	18.9-20.0
	D	16.8-17.8	-	-
F-560	FE	17.6	22.5	19.5

7.3.9.4. Progress and Problem Areas

Nissan appears to have the capability of achieving emission levels as low as 0.41 HC, 3.4 CO, 1.0 NOx with three different emission control systems; oxidation catalyst/conventional burn, oxidation catalyst/fast burn, and 3-way catalyst systems. At 0.41 HC, 3.4 CO, 0.4 NOx, only the oxidation catalyst system with the conventional burn engine would be eliminated from consideration.

The reported testing demonstrates excellent progress by Nissan toward the simultaneous achievement of good fuel economy and low exhaust emissions. The testing of the fast burn system represents one of the few times that a vehicle with a conventional, spark ignited engine has achieved the statutory emission levels without catalytic reduction of NOx. In addition, the fast burn vehicle had excellent fuel economy. The testing of a vehicle equipped with a 3-way catalyst system at statutory emission levels also revealed excellent fuel economy, but the system durability did not yet appear adequate. Other 3-way catalysts have been identified by Nissan in laboratory and engine dynamometer testing which may be considerably more active than the one tested on the durability vehicle.

The biggest problem remaining for Nissan is to demonstrate that the durability of their fast burn and 3-way catalyst systems are adequate. Should their durability be adequate, Nissan could then devote their development efforts to improved fuel economy. The lack of reported development of electronic spark and EGR systems is one area which could have an adverse impact on Nissan's fuel economy improvement potential in the future.

7.3.10. Peugeot

7.3.10.1. Systems Under Development

Peugeot also anticipates that the 1978 model year emissions standards will remain at the 1977 model year levels. The Peugeot submission also addressed the levels proposed in the House-Senate Conference bill and in the same time frame as proposed in that bill. Consequently, Peugeot did not discuss their engineering efforts to attain levels of 0.41 HC, 3.4 CO, 0.4 NO_x in their status report. This latest submission was less informative than previous Peugeot submissions.

For 1978, Peugeot will offer two gasoline engines for the low altitude and high altitude areas plus the same two engines recalibrated to meet the 1977 California standards. The 120.3 CID four cylinder engine will power the 504 series vehicles both sedan and station wagon, while the 163 CID V-6 engine will power the 604 series vehicles. The XD 4.94 138 CID Diesel engine will be offered on a 49-states basis for the 504 series vehicles. No mention was made concerning the use of the Diesel engine in California.

The 1977 Certification results for durability vehicles are shown in Table Peugeot-1.

Table Peugeot-1

FTP Results (gm/mi)

VIN	System	Miles (10^3)		HC	CO	NOx	MPG$_U$
77-261	Diesel	5		0.39	0.80	0.72	33.6
Family XD		50		0.41	1.30	1.19	25.9
			DF	1.02	1.65	1.26	0.77
77-601	AIR, OC	5		0.23	4.40	0.86	18.3
Family XNAC	EGR, EM, Decel Valve	50		0.19	5.00	0.81	19.6
Cal			DF	1.00	1.36	1.00	1.04
77-650	604 Sedan	5		0.23	2.90	0.68	15.44
Family	AIR, OC, EGR, EM	50		0.27	3.20	0.83	17.23
112.9 DA	Decel Valve						
Federal			DF	1.22	1.04	1.23	1.16
77-651	Same as 77-650	5		0.32	3.80	0.99	16.77
Family		50		0.42*	5.00	0.96	17.80
112.9 DA			DF	1.23	1.15	1.14	1.06
Cal							

---

* Exceeds the numerical value of the California 1977 Standards.

3-Way plus Oxidation Catalyst System

Peugeot is presently working on a fuel injected engine with an emission control system which incorporates an oxygen sensor, a 3-way catalyst, and, an oxidation catalyst with air injection before the oxidation catalyst. Little details were provided concerning the status of this development effort. Initial test results were about 0.41 HC, 7 CO, and 1 NOx. The vehicle will be started on durability testing soon.

No other systems were discussed.

Diesel Engine

Peugeot will be able to market their 138 CID Diesel engine in their 504 series vehicles at levels of 1.5 HC, 15 CO, 2.0 NOx. This engine incorporates a Ricardo Comet V combustion chamber and the Peugeot retardation system to reduce combustion noise and a declutching fan to improve fuel economy. Engine noise remains a major concern to Peugeot.

Peugeot maintains that at levels below 0.41 HC and 2.0 NOx, their Diesel engine will experience problems in attaining these levels simultaneously. Efforts to improve this situation include studies of a max-min governor rather than an all speed governor, a new improved injection pump, and modifications to the basic engine. These modifications include thermal insulation of the combustion pre-chamber, improved air induction, modified combustion chamber shape, and suppression of secondary fuel injection.

Peugeot reported that their initial results with the thermally insulated combustion pre-chamber were disappointing. The apparent lack of success is attributed to reduced compression ratio stemming from a poor heat barrier between the main combustion chamber and pre-chamber. Further thermal insulation work is contemplated.

Additional development work is underway to improve the air induction by modifying the intake and exhaust camshaft profiles. Also, reduced piston cavity volume will be studied.

All of the above developments, except thermal insulation, have been incorporated into a test vehicle which produced the following zero mile results: 0.25-0.30 HC, 1.63 CO, 2.1 NOx when using French fuel oil. Using 2D fuel could cause the values for HC and NOx to be higher. Durability testing has been started.

No cost or fuel economy data were presented for future Peugeot systems.

7.3.10.2. Systems to be Used at Various Emission Levels

At levels of 1.5 HC, 15 CO, 2.0 NOx, Peugeot will use the same systems for both their gasoline and Diesel engines as were marketed in 1977.

At 0.9 HC, 9 CO, 2.0 NOx, Peugeot did not address this level but it is clear these levels can be attained by the present 1977 vehicles.

The 0.41 HC, 9 CO, 1.5 NOx levels should not present any difficulty for Peugeot's gasoline engines, but Peugeot is very close to the 0.41 HC level with their Diesel durability vehicles now at high mileage.

To achieve levels of 0.41 HC, 3.4 CO, 2.0 NOx, Peugeot will use the same systems they plan to use at California levels for 1978, i.e., oxidation catalyst, EGR, air pump, a deceleration throttle opening system, and a new carburetor. The location of the catalyst and composition of the catalyst may be modified, and an automatic enrichment shutter for cold starting will also be incorporated.

Fuel economy and costs will be comparable to 1977 model vehicles.

At levels of 0.41 HC, 3.4 CO, 1.0 NOx, Peugeot will use a fuel injection, 3-way catalyst, O_2 sensor plus oxidation catalyst system. They anticipate that the O_2 sensor will have to be replaced every 15,000 miles. Fuel economy is predicted to be 1 MPG better than the present California vehicle fuel economy range of 16.7-17.8 MPG on the urban cycle when the technology is developed. The increased costs for this system is intended to be 10%. There was no discussion of the Diesel engine at these levels nor any discussion of levels more stringent than those for either the gasoline or Diesel engine.

7.3.10.3. Durability Testing Program

Peugeot did not report any durability test data. A summary of the 1977 Certification durability test data can be found in Table Peugeot-1.

Problems and Progress

Peugeot's progress during the past year has been disappointing as compared to the promise shown in last year's status report. The aggressiveness shown previously in attempting to lower HC and NOx emissions from Diesel engines seems to be lacking. The reported HC penalty encountered with the thermally insulated combustion chamber may have been a disappointment to Peugeot.

It was difficult to assess Peugeot's progress towards achieving statutory standards due to their report brevity, but it is encouraging to note their efforts with 3-way plus oxidation catalyst system.

Peugeot may have difficulty meeting emission levels of 0.41 HC and 1.5 NOx with their Diesel engine. They also will have to improve the basic calibration on the 3-way plus oxidation catalyst system to achieve statutory levels.

7.3.11. Renault

7.3.11.1. Systems Under Development

Renault indicates that they expect that the 1977 model year emission standards will be applicable in the 1978 model year. Consequently, much of the emission control hardware Renault used in 1977 will be used again in 1978 and possibly post-1978 model years. Renault uses air injection, EGR, and oxidation catalysts in combination as standard emission control equipment. The proposed 1978 model year systems offered by Renault are shown in Table Renault-1.

3-Way Catalysts

Renault was an early leader in 3-way catalyst technology and Renault continues to specify the 3-way catalyst as their first choice for a system to meet emission levels of 0.41 HC, 3.4 CO, 1.0 NOx and lower. There was no evidence in the Reanult submission that any other system is under active consideration, with the exception of the possible use of a 3-way plus oxidation catalyst plus air injection. Renault has not determined if it will be necessary to use this latter system.

Table Renault-1

1978 Model Year Systems

Engine Family	CID	49-State or California	Fuel System	AIR	EGR	Ox. Cat.
810R	79	49s	Carb	yes	yes	no
843R	101	49s	Carb	yes	yes	no
843FIR	101	49s	EFI*	yes	yes	no
140RC	163	49s	FI+	no	yes**	yes
810RC	79	Cal.	Carb	yes	yes	yes
843RC	101	Cal.	Carb	yes	yes	yes
140RCA	163	Cal.	FI+	yes	yes**	yes

* Bosch L-Jectronic

** Proportional EGR

+ Bosch K-Jectronic

While the details of Renault's work on 3-way catalyst systems remained sketchy, they did report data which showed the results of laboratory test program for 3-way catalyst selection.* This screening program culminated in the apparent selection of an Engelhard TWC-16 as the production 3-way catalyst. There were data that indicated that other potential 3-way catalysts had higher conversion efficiencies but were rejected for durability reasons. No details concerning the composition of the catalysts used in the screening test were provided.

Hot start CVS testing of 3-way systems have shown the following results.

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* During the discussion of the 3-way catalyst screening tests, Renault provided information which indicated that several platinoids (platinum, palladuim, ruthinium, rhudium) and oxides of transition metals such as nickel, iron, cobalt, copper, chrome/cerium and other rare earth metal are mounted on a large surface aluminum support which may or may not be stabilized by other oxides such as lanthanum, barium, and magnesium.

Table Renault-2
3-way Catalyst Test Results

Hot Start FTP (gm/mi)

Engine	HC	CO	NOx	MPG$_u$	Remarks
79 CID	0.06	2.5	0.59	-	
101 CID	0.2	2.0	0.30	22-23	L-Jetronic EFI
"	0.3	2.37	0.38	20.9	20K miles
163 CID	0.4	3.4	1.32	14.5	K-Jetronic FI*

---

* Attempt to adapt the Volvo system to Renault 30 vehicles, no system optimization.

Renault presented no data concerning O_2 sensor durability or system optimization to achieve levels of 0.41 HC, 3.4 CO, 0.4 NOx.

7.3.11.2. Systems to be Used at Various Emissions Levels

The systems Renault plans to use at the various emission levels are found in Table Renault-3 along with their fuel economy estimates. Renault indicated that these various levels could be met in the time frame indicated in the House-Senate Conference bill. No mention was made of developments or systems targeted at statutory levels.

7.3.11.3. Durability Testing

Renault reported no durability test data. Renault presented the 1976 and 1977 durability and data vehicle emissions and fuel economy results which can be found in Table Renault-4.

Table Renault-3

Systems to be Used at Various Emission Levels

Level	Model Year	Model line/ Eng. (CID)	System(s)	Fuel Economy Penalty
1.5 HC	1978	5/79	Carb, AIR, EGR	Baseline
15 CO		12/101*	Carb, AIR, EGR	
2.0 NOx		17/101	EFI, AIR, EGR	
		30/163	EFI, EGR, OC	
0.9 HC		Not specifically addressed		No penalty
9 CO		Assumed same model line would		
2.0 NOx		be offered in 1978		
0.41 HC	1978	Would use 1977 California		5%
9 CO		only vehicles at this level		
1.5 NOx				
0.41 HC	1979-	5/79	Carb, AIR, EGR, OC**	No penalty
3.4 CO	1980	17/101	EFI, AIR, EGR, OC	
2.0 NOx		30/163	EFI, AIR, EGR, OC	
0.41 HC	1981	5/79	Carb, 3-way, O_2 sensor	5 to 7%
3.4 CO		17/101	EFI, 3-way, O_2 sensor	improvement***
1.0 NOx		30/163	EFI, 3-way, O_2 sensor	No penalty#
0.41 HC	?	No discussion at this level		
3.4 CO				
0.4 NOx				

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* To be dropped after 1979 model year

** Lower compression ratio

*** If system development is completed

# If system is not developed

Table Results-4

1976 & 1977 Durability and Data Vehicle Emissions Level and Fuel Economy

			HC			CO			NOx			MPG_U			MPG_H
VID	Model/CID	Trans	Mileage 4 or 5K	Mileage 50K	Range	Mileage 4 or 5K	Mileage 50K	Range	Mileage 4 or 5K	Mileage 50K	Range	Mileage 4 or 5K	Mileage 50K	Range	Mileage 4K
340	5/79	M4	1.27	1.33	1.13–1.38	12.2	13.1	11.3–13.6	1.81	1.71	1.65–1.84	27.7	27.0	26.0–27.7	-
367	17/101	M5	0.95	0.87	0.86–1.14	11.7	12.4	8.6–13.0	1.60	1.75	1.60–1.89	18.6	19.7	17.4–19.9	-
342*	5/79	M4	0.381	0.539	.265–.578	3.46	3.31	2.40–3.76	1.63	1.65	1.39–1.82	23.8	25.8	23.0–25.8	-
*California target: 0.41 HC/9 CO/2.0 NOx @50,000 mi															
TP 751	5/79	M4	1.34	-	-	11.8	-	-	2.00	-	-	25.6	-	-	41.0
TP 750	5/79	M4	1.28	-	-	13.3	-	-	2.02	-	-	26.5	-	-	40.6
770	17/101	M5	1.32	-	-	7.9	-	-	1.53	-	-	30.8	-	-	36.0
TP 95	30/163	A3	0.95	-	-	6.2	-	-	1.74	-	-	25.4	-	-	30.8
TP 96	30/163	M4	1.31	-	-	7.9	-	-	1.91	-	-	25.0	-	-	34.6

7.3.11.6. Problems and Progress

It was difficult to ascertain from the Renault status report the progress Renault has made during the past year. While it appears that Renault has made some progress with their 3-way catalyst system, much more durability testing is required before their capability to meet low emission levels can be determined. Indeed, EPA only has Renault's assurances that emission levels more stringent than the present levels can be met. A positive note was the statement by Renault that they were working with Volvo on perfecting a 3-way catalyst system.

7.3.12. Rolls-Royce (RR)

7.3.12.1. Systems Under Development

Rolls-Royce Motors is a comparatively small company with annual sales in the USA of about 1100 cars. Therefore, they have concentrated on projects which offer good prospects for success with priority given to meeting standards to assure continuity of production. RR's aim is to adapt and develop proven techniques resulting from basic research carried out by the major manufacturers who have the necessary financial resources. Close liaison is maintained with component suppliers and other car manufacturers.

RR also assumes that the 1977 legislated standards will be applicable in 1978. Hence, they plan to continue marketing their conventional V-8 (412 CID) engine, with twin SU carburetors, HEI, air pump, BPEGR, and dual Johnson Matthey 230 oxidation catalysts. The systems that RR is presently working on are discussed below.

Oxidation Catalyst

RR introduced a rhodium/platinum oxidation catalyst with their 1977 vehicles. Because they intend to use this catalyst at the present emission levels of 1.5 HC, 15 CO, 2.0 NOx, they have not conducted additional development efforts on this catalyst other than system optimization with increased EGR rates to meet 0.41 HC, 3.4 CO, 1.0 NOx. 1977 Certification levels can be found in Table RR-1. A vehicle with this catalyst was tested for hydrogen cyanide at EPA Research Triangle Park. The results are summarized in Table RR-2.

Table RR-1

RR 1977 Certification Test Results

Engine Family	FTP Results (gm/mi) HC	CO	NOx	Fuel Economy MPG_u	MPG_h
IF 49 states	0.197	1.253	1.97	10.7	12.3
IC Calif.	0.186	1.578	1.10	8.7	11.4
IF 49 state high alt.	0.41	5.9	1.56	8.7	11.4
Durability vehicle	0.18-.33	1.5-2.9	0.90-1.35	8.22-9.13	-
DFs	0.705	0.972	0.775	1.103	-

Table RR-2

HCN Testing of RR Production Catalysts

Freeway test:	Normal operation	0 - 0.79 mg/mile
	Malfunctioning (Air injection disconnected)	4.89 - 31.0 mg/mile
	EPA tentative max. permissable limit	300 mg/mile
Garage test:	Normal operation	0
	Malfunctioning (Air injection disconnected)	0 - 0.934 mg/mile
	EPA tentative max. permissible limit	15 mg/mile

3-way Catalysts

At levels of 0.41 HC, 3.4 CO, 0.4 NOx, RR has selected as their first choice system the new aluminum V-8 444 CID engine, Bosch K-Jetronic fuel injection, a Bosch O_2 sensor for closed loop electronic control, HEI, BPEGR, and an unspecified 3-way catalyst. Low mileage vehicle results were 0.25 HC, 2.5 CO, and 0.25 NOx with a city fuel consumption of 8.5 MPG. Cold driveability was considered poor.

Work continues on evaluating Johnson Matthey, Engelhard, and Degussa 3-way catalysts along with various engine compression ratios and induction system features. RR feels that the fuel injection system could not be introduced into production before 1980 model year even on a crash basis. RR projects 1982 as the time frame for introduction of this system. No costs were estimated. Production system durability is targeted to start in September 1977.

3-way Catalysts plus Oxidation Catalyst

Since the last status report, RR has evaluated a prototype 3-way catalyst plus oxidation catalyst system with switched air injection. They reported the results were disappointing. RR will continue to work on this system but they feel other methods were more promising. No emissions or fuel economy results were reported.

Other Systems

Start Catalysts

RR now is concentrating their start catalyst work in association with their fuel injection and their 3-way catalyst efforts. To date they have not seen any emissions benefits using start catalysts and air switching with their 3-way catalyst system.

EGR System

RR evaluated the Deutsche Vergaser Gesellschaft (DVG) EGR system in comparison to the Rochester Products BPEGR system. DVG system produces no advantage, according to RR, over the Rochester system.

Dual Fuel System

RR has abandoned work with the Mobil LEF system due to better results with their 3-way system and the LEF's increased complexity.

Modulated Air Injection System

Work on a modulated air injection system with closed loop control from an oxygen sensor in the exhaust system has reached only the project design stage. Efforts have been concentrated on other work and this project remains in the formative stage.

7.3.12.2. Systems to be Used at Various Emission Levels

The systems RR would use at the various emissions levels can be found in Table RR-3 along with explanatory remarks from the RR status report submission.

Table III-1

Systems to be Used at Various Emission Levels

Level	System	Projected Fuel Economy Penalty	Introduction Date	Remarks
1.5 HC, 15 CO, 2.0 NOx	Present 1977 system for 48 states both high and low altitude	None	1978	No difficulty in achieving these levels
0.9 HC, 9 CO, 2.0 NOx	Same as above	0	1978	No difficulty
0.41 HC, 9 CO, 1.5 NOx	Present 1977 California vehicle calibration achieves these levels	18.7% City 7.3% Highway	1978	Cannot be met at high altitude at present. Lead time of 12 months needed to introduce nationally
0.41 HC, 3.4 CO, 2.0 NOx	Oxidation catalyst + EGR	Present 1977 system durability vehicle meets these levels with a fuel consumption range of 8.2 - 9.1 (15 - 23% loss from fuel economy vehicle)	1978 ?	Both 1977 Federal & California vehicles meet these levels now. Cannot meet levels at high altitude.
0.41 HC, 3.4 CO, 1.0 NOx	Oxidation catalyst, EGR, and new 444 in^3 engine	20%	1980 ?	Needs adequate lead time
0.41 HC, 3.4 CO, .4 NOx	3-way closed loop EFI, O$_2$ sensor	?	1982	Achieved experimentally

7.3.12.3. Durability Testing

RR presented no durability data for any of their experimental systems.

7.3.12.4. Problems and Progress

At NOx emission levels higher than 1.5 gm/mi, it would appear that RR has the capability of achieving sufficient HC and CO control to certify vehicles at low altitude with their present 1977 model year emission control system. Additional work will be necessary to achieve NOx levels of 1.0 gm/mile while reducing the presently high fuel consumption penalties associated with their first choice control system for 1.0 NOx.

RR is experiencing problems with 3-way catalyst and O_2 sensor durability which makes them pessimistic about achieving statutory levels prior to 1982.

7.3.13. Saab

7.3.13.1. Systems Under Development

During the past year, Saab has continued to aggressively pursue 3-way catalyst technology. Saab, with their low inertia weight model line and the already accepted cost penalty for fuel injection, is in a position to actively develop 3-way catalyst systems. Saab has also introduced a 3-way catalyst system on their 1977 model year California vehicles.

Consequently, Saab has not addressed systems other than the 3-way catalyst system. In fact they state, "The basic reason why other possible systems have been abandoned is that we (Saab) are convinced that the 3-way catalyst system offers the best solution for meeting very stringent emission levels and it does this without requiring any compromise with respect to driveability and fuel economy."*

Saab feels that stratified charge engines are not feasible for two reasons, namely low sales volume which cannot justify large investments in development and tooling and the stratified charge engine's non-compatibility with a 3-way catalyst system.

Saab also has not tested lean burn systems "because lean mixtures always imply a risk of bad driveability, loss of performance and fuel economy and it has not been proven that 1.0 gm/mi NOx can be obtained at the same time as performance and driveability are at an acceptable level."**

3-Way Catalyst System

Since Saab feels that a 3-way catalyst system is the only acceptable solution to meet stringent emission standards, they have concentrated on developing this system. In terms of emissions, Saab has changed the engineering design goals from 50% of any emission level to 70% on prototype vehicles. Saab also has engineering targets to improve fuel economy to meet prescribed mileage levels, to maintain good driveability and to minimize the system cost impact. Saab feels that compared to their present 1977 systems, the 3-way catalyst system's only drawback will be cost. Compared to an uncontrolled engine, the 3-way catalyst will have a performance loss of 10-15%, fuel economy penalty of 10%, and be 300 dollars higher on the sticker price, according to Saab.

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* Saab-Scania AB 1976 Status Report, page 4.

** ibid.

Saab presently has three 3-way catalyst system vehicles and two turbocharged 3-way catalyst system vehicles under component and system testing at their Trollhatten assembly plant, headquarters for Saab's Passenger Car Division. They also have four 3-way catalyst vehicles, one of which is at Engelhard and one at Bosch, plus three turbocharged engines with 3-way catalyst vechicles under system testing at Sodertalje, their engine assembly plant and laboratory. Three other vehicles are used specifically for durability testing of 3-way catalyst systems. Two of these vehicles, numbers 745 and 797, have completed 50,000 miles and the third vehicle has completed at least 40,000 durability miles using the proposed production Engelhard TWC-16 3-way catalyst. Prior to these latest test results, these vehicles had accumulated mileage using the Engelhard TWC-98 3-way catalyst. The test results can be found in Table Saab-1. Saab noted that the problems of worn exhaust valve guides and seats have been solved by using sodium-cooled exhaust valves.

Saab described the driveability rating of their 3-way catalyst vehicles. The driveability ratings for model year 1975 to 1981 vehicles are summarized in Table Saab-2.

Table Saab-1

Saab Three-Way Catalyst Durability Test Fleet*

VIN	System	Miles (10^3)	HC	CO	NOx	MPG
			—FTP Results (gm/mi)—			
745	EFI, O_2 sensor	0	0.07	2.47	0.96	20-22
Test No. 130	TWC-90	4	0.10	2.70	1.73	
	Auto Trans.	5	0.18	2.71	1.65	
		11	0.23	6.48	0.90	
		16	0.14	3.96	0.87	
		21	0.14	2.76	0.80	
		24	0.14	2.70	0.85	
		27	0.18	2.72	0.73	
		31.8	0.31	2.83	0.70	
797	EFI, O_2 sensor	0	0.13	2.24	0.97	21-22.5
Test No. 131	TWC-90	5	0.25	2.70	0.82	
	Auto Trans.	10	0.23	4.85	0.90	
		15	0.30	5.85	0.90	
		21	0.32	4.50	1.12	
		25	0.65	4.58	1.27	
	Worn exhaust valves	27.5	0.83	8.02	0.90	
800	EFI, O_2 sensor	0	0.21	4.06	0.35	20-23
Test No. 132	TWC-90	2.5	0.21	2.97	0.60	
	Manual Trans.	5	0.32	2.86	0.98	
		6.7	0.24	2.25	1.13	
		11	0.23	1.80	1.15	
	Cold start problems	13	0.43	3.15	1.15	
		30	0.27	3.60	1.05	
		32	0.29	3.70	0.75	
		35	0.32	3.70	0.98	
		40	0.45	8.13	0.60	

Table Saab-1 (cont.)

VIN	System	Miles (10^3)	HC	CO	NOx	MPG_u
745	EFI, O_2 sensor	0	0.03	2.77	0.09	
Test No. 133	TWC-16^2	2	0.16	2.80	0.60	
	Auto Trans.	6	0.51	7.20	0.25	
	Cyl. heads	11	0.23	3.60	1.05	
	changed 6 & 36K	14	0.25	2.25	0.45	
	miles	22	0.28	5.85	0.30	
		27	0.29	5.40	0.30	
	Before maintenance	36	0.65	5.40	0.45	
	After maintenance	36	0.16	2.25	1.05	
		42.5	0.18	3.60	0.90	
	*	50	0.39	5.93	0.95	
797	EFI, O_2 sensor	0	0.15	3.06	0.22	
Test No. 134	TWC-16^2	4	0.23	4.23	0.30	
	Auto Trans.	8	0.37	6.10	0.33	
		14	0.25	5.40	0.35	
		19	0.26	5.40	0.38	
		24	0.27	5.85	0.38	
		28	0.26	5.40	0.38	
		34	0.27	5.50	0.75	
		39	0.26	5.50	0.90	
		43	0.25	5.40	0.75	
		46	0.26	5.90	0.70	
		50	0.23	4.35	0.95	
800	EFI, O_2 sensor	0	0.21	4.54	0.10	
Test No. 135	TWC-16^2	1.6	0.38	5.40	0.28	
	Man. Trans.	3	0.21	2.30	0.45	
	Exh. Valve failure	4.6	0.47	6.80	0.75	
		7	0.30	4.50	0.82	
	Ignition cables broken	11	0.57	5.85	0.45	
	" " "	14	0.50	7.40	0.65	
800	EFI, O_2 sensor	0	0.18	2.11	0.08	
Test No. 136	TWC-16^2	5	0.27	3.78	0.15	
	Man. Trans.	11	0.16	5.85	0.15	
		25	0.30	5.60	0.23	
		31	0.31	5.90	0.15	
		40	0.46	6.73	0.33	

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* All vehicles targeted to 0.41 HC, 9 CO, 1.5 NOx.

Table Saab-2

Drivability For Different MY Vehicles*

MY	Federal		California	
	Cold	Warm	Cold	Warm
'75	5.5	6.0	5.5	5.0
'76	6.5	7.0	6.5	5.5
'77	6.5	6.5	6.5	8.0
'78	6.5	6.5	6.5	8.0
'79-'80	5.0	8.0	5.0	8.0
'81	5.0	8.0	5.0	8.0

Acceleration Performance Comparison

Cal MY 1977 to Cal MY 1976 (automatic gearbox)

Acceleration Range	0 - 60 MPH	30 - 60 MPH	1/4 mile
Improvement Part throttle	5.9 sec	7.2 sec	2.4 sec
Improvement Full throttle	3 sec	1.5 sec	1.1 sec

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* Drivability Ratings

1-3	Very Bad
4	Bad .
5	Limit
6	Acceptable
7	Well acceptable
8	Good
9	Very good
10	Excellent

For Federal cars the achieved performance improvement was somewhat offset by the necessity to use proportional EGR on all model year 1977 cars. The 3-way catalyst system for California model year 1977 gives a pronounced warm engine driveability improvement compared to the model year 1976 system. For model years 1979 to 1980 driveability will be impaired by the necessity to use lean air-fuel ratios at cold start. The driveability ratings for model year 1979 to 1981 are anticipated values as the final specifications have not yet been determined.

Saab also presented data comparing the emission results between the TWC-9D and the TWC-16 at various noble metal loading and Pt/Rh ratio. These results are presented in the table below.

Table Saab-3

CVS - results with TWC-16 and TWC-9D, 15gm/cu ft. loading, aged to 600 hrs = 50,000 miles

	CVS Results			
Conditions	HC	CO	NOx	Fuel Economy - MPG$_u$*
Without catalysts	1.29	16.0	2.74	21.0
TWC-16, 50 gm/cu ft. aged 600 hrs	0.278	4.68	0.214	21.6
TWC-16, 15 gm/cu ft. aged 370 hrs	0.291	5.73	0.752	20.8
aged 625 hrs	0.357	6.67	0.786	21.6
TWC-9D, 15 gm/cu ft. aged 370 hrs	0.218	5.92	0.769	20.6
aged 625 hrs	0.431	7.01	0.790	21.6

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*Reported as (1/10km) in the Saab Status Report and converted to MPG$_u$ assuming these were corresponding CVS test results.

The test results with the different catalysts show that the TWC-16 with 50 gm/cu ft. loading gave the best overall results. If the TWC-16 tested by Saab is like other TWC-16 catalysts, the Pt/Rh ratio should be 5/1. The data in Table Saab-3 show that both Pt/Rh ratio and loading are important, with Pt/Rh ratio being possibly less important than total loading. If one compares the results from the TWC-9D (19/1 Pt/Rh) and the TWC-16 at 15 gm/cu ft. the results are fairly close at 625 hours: 0.431 HC vs 0.357 HC, 7.01 CO vs 6.67 CO, 0.790 NOx vs 0.786 NOx. These results show almost no difference for NOx and a slight HC and CO advantage for the catalyst with the higher Rh content (TWC-16). Comparing the two TWC-16 catalysts, it can be seen that the results for NOx are much different (0.214 NOx vs 0.786 NOx) with a decided advantage for the more highly loaded catalyst. To complete the comparison, results on a 50 gm/cu ft. TWC-9D catalyst would have been helpful. However, Saab did not report these results.

Saab also tested the influence of manganese additives on catalyst and oxygen sensor aging. Their results show a very small effect on the catalyst but the sensor shows a slight deterioration. In CVS-testing this gives somewhat higher HC and CO emissions and lower NOx emissions. Fuel specification and test results are shown in Table Saab-4. Saab also has tested their 3-way catalyst for sulfate emissions and measured H_2SO_4 content as 0.00 gm/mi in all tests. Saab does not have the facility to test for hydrogen cyanide.

Fuel economy figures from Saab's durability test vehicles are shown in Table Saab-5.

Table Saab-4

CVS-results with TWC-16, loading 15 gm/cu ft. and 50 gm/cu ft., aged on motor-bench for 600 hours (about 50,000 miles) with fuel containing manganese additives

Fuel: Certification fuel - 77 but with 0.5 gm MMT/USG (0.125 gm Mn/USG) added

Test cars: 658, auto., CVS-results without catalyst (gm/mi).
HC = 1.05 CO = 14.8 NOx = 3.32

686, manual, CVS-results without catalyst (gm/mi):
HC = 1.38 CO = 16.0 NOx = 2.83

Results

After 350 hours, car 658

	50 gm/cu ft.			15 gm/cu ft.		
	HC	CO	NOx	HC	CO	NOx
Normally aged cat.* and O_2 sensor	0.28	4.01	0.64	-	-	-
Mn-aged cat. and O_2 sensor	0.34	5.83	0.56	0.46	6.00	0.99

After 600 hours, car 686

	50 gm/cu ft.			15 gm/cu ft.		
	HC	CO	NOx	HC	CO	NOx
Normally aged cat. and O_2 sensor	0.25	3.78	0.22	0.36	6.67	0.79
Mn-aged cat. and normal O_2 sensor	0.23	4.66	0.24	0.28	5.85	0.78
Mn-aged cat. and O_2 sensor	0.23	5.27	0.20	0.31	6.15	0.64

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* 600 hours

Table Saab-5

Saab Fuel Economy Data from Various Test Vehicles

EGR + Pulse Air

Vehicle No.	Emission Targets	Trans.	MPG_u	MPG_h	MPG_c	Norm Drive*	Mean Over Miles
230	1	M	18-20	25-26	20.5-22.5	23-24	300-600
655	"	A	16-18	21-22	18-20	21-22	300-600
536	"	A					
014	"	M				30.7	21,000
716	"	A				20.5	33,000
771	"	M				22.4	37,000

Compared to MY 1977 EPA Result (Saab reported)

	MPG_u	MPG_h	MPG_c
M	21	31	25
A	19	23	20

3-Way Catalyst Vehicles

Vehicle No.	Emission Targets	Trans.	MPG_u	MPG_h	MPG_c	Norm Drive*	Mean Over Miles
658,686	4	A,M	19-21	26-28	22-24	23-25	300-600
018	4	M				21.6	18,000
019	4	A				18.9	16,000
059	4	M				22.6	15,007
745**	3	A				21.6	84,000
797**	3	A				22.6	88,000
800**	3	M				23.5	87,000
839***	4	M	18-19	25-26	20.5-21.5	-	
168**	4	M				23.5	800

Compared to MY 1977 3-way cat. EPA Results (Saab reported)

	MPG_u	MPG_h	MPG_c
M	23	33	27.5
A	21	25	22.8

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* Measured fuel consumption on non-AMA durability test route.
** Durability vehicle.
*** Turbocharged engine

Emission Targets

1.5 HC/15 CO/2.0 NOx = 1
0.9 HC/9 CO/2.0 NOx = 2
0.41 HC/9 CO/1.5 NOx = 3
0.41 HC/3.4 CO/2.0 NOx = 4
0.41 HC/3.4 CO/1.0 NOx = 5
0.41 HC/3.4 CO/ 0.4 NOx = 6

Saab presented, in the following table, the first cost of the emission control components of the model year 1978 and model year 1979-81 systems.

These costs are increased over the 1974 system except for the cost for the turbocharged version. In that case the cost increments are to be compared with the European version (uncontrolled) of the turbocharged vehicle.

Table Saab-6

Item	Model Year 1978 Feder[illegible]	 California	Turbo.	Model Year 1979-81 50 State
Closed loop control	--	105	105	105
Oxygen sensor	--	15	15	15
Exhaust manifold	--	14	--	14
3-way converter	--	81	85	81
Heat shield	--	4	4	4
Pulsair	11	--	--	--
EGR-proportional	24	--	--	--
Alternate EGR	(14)	--	--	--
Decel. system	--	--	12	--
Service Ind.	2	2	2	2
Assembly costs	3	5	7	5
Value Added	40 (30)	226	230	226
Sticker Price	$60 (45)	$239	$345	$339

Operating Costs

1. Fuel and Lubricant Costs

A comparison of composite fuel economy (miles/gallon) for the Saab engine families as compared to model years is given in the following table:

Engine Family	1977	1978	1979-81
Manual, Federal	25	22	--
Automatic, Federal	20	20	24
Manual, California	27.5	27.5	--
Automatic, California	22.8	22.8	--

Note: California fuel economy is better than Federal fuel economy due to improved emission control technology.

Table Saab-6 (cont)

Based on the previous information, the following shows fuel costs for 50,000 miles of operation, assuming a fuel cost of $.60/gallon:

	1977	1978	1979-81
Manual, Federal	$1,200	$1,360	-
Automatic, Federal	1,500	1,500	$1,648
Manual, California	1,086	1,086	-
Automatic, California	1,314	1,314	-

There will be no change in lubricant costs.

2. Maintenance Costs Other than Catalyst Replacement

The anticipated maintenance costs for 1977 and 1978 through 1981 as compared to 1974 models are given as follows:

	1974		1977		1978-81	
	Parts	Labor	Parts	Labor	Parts	Labor
Federal	$188	14 hrs	$193	26.4 hrs	$241	26.4 hrs
California	$188	14 hrs	$241	26.4 hrs	$--	--

The maintenance cost includes 3 changes of the oxygen sensor at 15,000 mile intervals at a cost of $16/change.

3. Catalyst Replacement Cost

The estimated life of the 3-way catalyst used in the O_2 sensor control closed loop system is over 50,000 miles.

The initial cost of the catalyst, including the container, is approximately $70. Although the replacement cost has not yet been determined, it is estimated to be about $200. One-third of an hour labor would be required for replacement of the catalyst.

Turbocharged Engine

Saab maintains that the idea behind the turbocharged engine is not basically to improve emissions and fuel economy but to maintain those properties at a higher performance level. When the 3-way catalyst system was adapted to the turbocharged engine, it was found that very few changes were necessary, indeed the exhaust emission results were very similar to the non-turbocharged version. Saab speculates that the reason for this is that the exhaust inlet temperature at the catalyst is lower than on the non-turbocharged which is compensated for by the lower gear ratio in the turbocharged vehicle. Typical emission and fuel economy data are shown in Table Saab-7. It should be noted that these cars have not yet been optimized with respect to emissions. Saab plans to test market 50 of these vehicles in the near future.

Table Saab-7

Turbocharged Vehicle Emissions and Fuel Economy Results

		FTP Results (gm/mi)			Fuel Economy		
VIN	System	HC	CO	NOx	MPG_u	MPG_h	MPG_c
839	Turbo, no cat. 3 tests	1.09	16.2	2.16	17.4	-	-
	w/3-way cat. 18 tests	0.40	3.1	0.86	17.2	23.4*	19.2*
	839 w/new engine wrong decel valve setting, 4 tests	0.35	4.2	1.02	18.5	25.2	21.1
	839 w/o.g.	0.24	4.2	0.62	17.7	-	-
	tune	0.33	4.0	0.75	18.2	24.5	20.6
170	w/3-way cat	0.23	2.6	0.54	-	-	-
186	w/o cat	0.98	13.9	3.14	-	-	-
	w/3-way cat	0.30	3.5	0.27	-	-	-

* Two test results

7.3.13.2. Systems to be Used at Various Emission Levels

The systems Saab plans to use at the various emission levels can be found in Table Saab-8. Saab did not address levels of 0.41 HC, 3.4 CO, 0.4 NOx directly but did indicate that the 3-way catalyst system has potential at this level.

7.3.13.3. Durability Testing

The durability test results of vehicles equipped with a 3-way catalyst system are shown in Table Saab-1. Since Saab plans to introduce the 3-way catalyst system in California in May 1977, the durability testing for certification of this system is well underway. Typical test results for both the Federal and California vehicles can be found in Table Saab-9. It appears that Saab will have little difficulty achieving the 1977 emission levels and in fact may have a good chance to meet statutory levels in the very near future.

Durability testing of the turbocharged engine is just starting with none of the six vehicles presently under test having accumulated more than 6,000 miles. One additional vehicle is planned for durability testing.

Since Saab feels that the 3-way catalyst's durability will not be a problem, they have concentrated on solving the apparent durability problems of the O_2 sensor. Saab has developed four tests to establish durability under high engine temperature conditions, ceramic failure at low temperature, thermal shock, and normal vehicle road testing. To date Saab reports that the production released sensor has reported few failures on the various test cycles or vehicle durability tests. Those sensors which have drifted, drifted to the rich side of stoichiometric. Durability test fleet mileages on oxygen sensors have ranged from 11,000 to 50,000 miles on durability vehicles.

Table Saab-6

Systems to be Used at Various Emission Levels

Naturally Aspirated Engines

Item	1978 1.5 HC, 15 CO, 2.0 NOx	1978 0.41 HC, 9 CO, 1.5 NOx	1979-80 0.41 HC, 3.4 CO, 2.0 NOx	1981* 0.41 HC, 3.4 CO, 1.0 NOx
Compression ratio				
-8.7		X	X	X
-9.25	X			
Exhaust manifold				
-Single		X	X	X
-Two-branch	X			
Air Injection				
-Pulsair	X			
EGR				
-Proportional	X			
-Double port	alternative**			
Catalyst: 3-way		X	X	X
Catalyst location:				
-Under floor		X	(X)	(X)
-Close to engine			X	X
Closed loop control-EFI		X	X	X
Fuel load enrichment		X	(X)?	(X)?
Service interval indicator	X	X	X	X

Turbocharged Engines

The turbocharged engines will be equipped with the same exhaust emission control system as used on the naturally aspirated engine with the following differences:

-Compression ratio will be 7.5:1
-Full load enrichment will not be
used after 1978
-A new deceleration control system will be used.

---

* Saab did not address 0.41 HC, 3.4 CO 0.4 NOx directly but feels the three-way system has potential to meet these levels.

** A vacuum transducer keeps the EGR valve open [illegible] it exceeds on high load accelerations and at sustained high loads EGR is shut off.

( ) To be determined.

Table Saab-9

1977 Durability and Data Vehicle Test Results*

Durability Vehicles, 99 GL Sed., 4 speed, 3000# I.W., 3.89 Rear Axle

VIN	System	Trans.	Miles (10^3)	FTP Results HC	CO	NOx	Fuel Economy MPG_u	MPG_h
99-086	FI/EGR/PAIR	M	5	1.34	6.4	1.81	17.7	23.3
			50	0.90	5.4	1.87	16.5	22.1
			Range	0.7-1.42	5.4-9.6	1.72-1.90	16.5-17.7	-
99-109	FI/3-way**	M	5	0.15	2.7	0.71	18.7	22.7
			45	0.35	5.0	0.82	17.6	-
			Range	0.15-0.45	2.7-6.4	0.30-0.93	15.5-19.6	-

Data Vehicles: Same as durability vehicles except axle equipped with automatic transmission.

VIN	System	Trans.	Miles (10^3)	HC	CO	NOx	MPG_u	MPG_h
99-121	FI/EGR/PAIR	M	4	0.89	8.3	1.70	21.9	31.8
99-087		A	4	1.29	8.8	1.91	16.6	22.3
99-107	FI/3-way	M	4	0.12	3.1	0.38	17.7	24.1
99-108		A	4	0.18	2.4	0.32	16.5	24.6

---

* Difficulties have been encountered with the Saab certification test results. Data have been discovered where Saab failed to record background emission levels during the FTP testing along with failure to comply with the 20 minute time limitation on measuring the bag emissions between Bags 2 and 3. Correction factors are being developed by the Certification Division to correct these data for the apparent anomalies.

** Three O_2 sensor changes approximately 15,000 miles each.

In order to stress the oxygen sensor at low ambient temperature conditions, a cold start test was conducted where the car was started three times a day from a cold state and driven hard until the engine reached normal operating temperature. Then the vehicle was stopped, the engine was cooled down to ambient temperature and the cycle repeated. The test was stopped after 221 cycles. The following test results were noted.

Before	HC 0.14	CO 2.36	NOx 0.19 gm/mi
After (221 cycles)	HC 0.24	CO 4.88	NOx 0.57 gm/mi

7.3.13.4. Progress and Problems

Saab has experienced exhaust valve sealing problems during the durability testing of the 3-way catalyst system. The inclusion of sodium cooled valves has helped avoid excess HC emissions on subsequent tests. Improved ignition cables were also necessary to alleviate a misfire problem also noticed during durability testing. Other than these minor problems, Saab has not reported the durability problems other manufacturers reported for the 3-way catalyst system. They have reported, like other manufacturers, that CO levels at 3.4 do not increase the chances of the 3-way catalyst sustaining emissions below statuatory levels for 50,000 miles.

Because Saab has already accepted the cost of fuel injection and produces vehicles with relatively low inertia weight, it is conceivable that Saab will be able to meet exhaust emission levels of 0.41 HC, 3.4 CO, 0.4 NOx in the near future. Saab's work to date indicates that they should have no trouble meeting levels below 1.0 gm/mi NOx with improved driveability and potentially improved fuel economy. Saab has aggressively developed the 3-way catalyst system and consequently has the potential for meeting the lowest emission levels proposed.

7.3.14. Toyo Kogyo (TK)

7.3.14.1. Systems Under Development

Rotary Engine

TK is pursuing the development of three rotary engine concepts. These are:

1. Lean Combustion System (LCS)
2. Compound Induction Step Control (CISC)
3. Rotary Stratified Combustion (ROSCO)

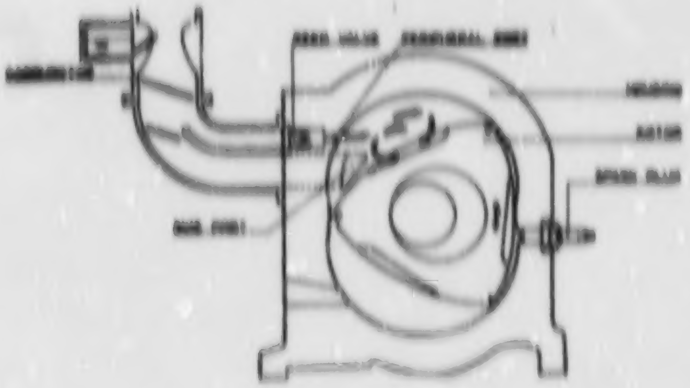
The LCS is the current production rotary used in both 49 state and California vehicles. It is used on their 3000 IW vehicles. The LCS replaced the older concept rich thermal reactor rotaries which suffered from poor fuel economy. The current LCS engine is a twin rotor, 80 cu in. unit with air injection, thermal reactor, and proportional EGR.

TK is working on several improvements to the LCS. These include improved gas seals, modified combustion chamber, and HEI. TK indicates that the LCS is capable of achieving emission standards as low as 0.41 HC, 3.4 CO, and 1.0 NOx. Table TK-1 shows emissions from an advanced version of the LCS.

Shown in Figure TK-1, the CISC is a carbureted engine that achieves a charge stratification by utilizing the natural swirl of the rotary and introducing the intake charge through a novel porting arrangement. As with the LCS, the CISC is equipped with air injection, thermal reactor, and EGR. TK indicates that the CISC is capable of NOx emissions in area of 0.7 to 0.8 gm/mi. It competes with advanced versions of the LCS at the 1.0 gm/mi NOx level where it reportedly has improved fuel economy and driveability over the LCS. Cost and producibility considerations, however, cause TK to favor the LCS at this level.

Table TK-1 shows emission and fuel economy results for the LCS and CISC calibrated for the 1.0 NOx level.

Figure TK-1*
Compound Induction Step Control (CISC)



* Automotive News, 10 January 1977, page 23.

Table TK-1

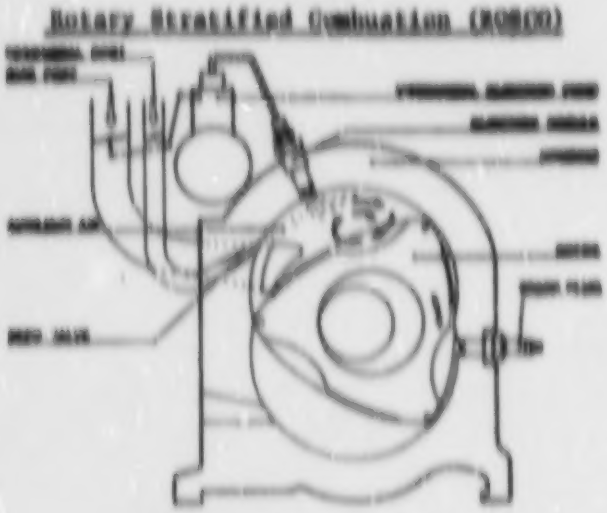
Rotary Engine Emissions

System	CID	IW	HC	CO	NOx	MPG_U	MPG_H
LCS	80	3000	0.21-.28	2.2-2.98	0.85-.90	19.4	31.8
CISC	80	3000	0.25	2.0	0.68	20.0	31.6
ROSCO	80	3000	0.3	3.1	0.34	17.0	29.5

The ROSCO engine accomplishes charge stratification by injecting fuel into the natural swirl of the rotary. The ROSCO system includes fuel injection, air injection, thermal reactor, and EGR. TK indicates that the ROSCO is capable of achieving statutory emissions. Table TK-1 shows emission results for a ROSCO system calibrated at this level. TK indicates that the current fuel economy penalty of the ROSCO can be reduced by the application of the improved gas seals and HEI that are currently being developed for the LCS. At present the ROSCO suffers about a 10% fuel economy penalty at the 0.4 NOx level. The driveability of the ROSCO at this level is reported to be good.

Figure TK-2*

Rotary Stratified Combustion (ROSCO)



* Automotive News, 10 January 1977, page 23.

Conventional Engines

TK's previous first choice system for NOx levels below 1.0 gm/mi was their Divided Chamber Stratified Charge (DISC) system. This system resembled the Honda CVCC. TK now reports, however, that a new system called the Stabilized Combustion System (SCS) has supplanted the DISC system for meeting the 0.4 NOx level. The SCS system is a derivitive of TK's system to meet the domestic Japanese 1978 emission standards. This system uses a proprietary technique to substantially increase EGR tolerance. This reportedly allows higher EGR rates with a resultant improvement in NOx control without accompanying HC or driveability penalties. TK has also designed a new EGR system to be used in conjunction with the SCS system. This EGR system has more proportional flow characteristics.

TK intends to use a 3-way catalyst along with the SCS at the statutory emission level. This would be a carbureted, open loop system. TK reported laboratory screening tests rf many 3-way catalyst formulations.

7.3.14.2. Systems to Meet Various Emission Levels

Table TK-3 shows TK's first choice systems to meet the various emission levels for rotary and conventional engines.

7.3.14.3. Durability Testing

TK provided no durability test data.

7.3.14.4. Progress and Problems

TK appears confident that it has a firm grip on the technology needed to meet any of the various future standards under consideration. Questions do remain in TK's mind concerning cost, fuel economy, and development and production schedules.

The SCS system for the conventional engine is an example of TK's technical talents and willingness to expend resources on research and development.

One weak point for TK is their lack of durability testing on their advanced systems such as the ROSCO and SCS.

Table IX-3

First Choice Systems to Meet Various Emission Levels

Level HC	Level CO	Level NOx	Engine	System	Fuel Economy*	Cost
0.41	9	1.5	Rotary	[illegible]: Thermal Reactor + AIR + EGR	-1 to -10%	$5-8
			Conv. 98 cu in.	AIR + Exhaust Port Liners	0 to -15%	$30-$60
			Conv. 77 cu in.	AIR (aspirator type) + Ox. Cat. + EGR	0 to -15%	$30-$60
0.41	3.4	2.0	Rotary	[illegible]: Thermal Reactor + AIR + EGR	-1 to -10%	
			Conv. 98 cu in.	AIR + Ox. Cat. + Exhaust Port Liners + EGR	0 to -15%	$30-$60
			77 cu in.	AIR + Ox. Cat. + EGR	0 to -15%	$30-$60
0.41	3.4	1.0	Rotary	[illegible]: Thermal Reactor + AIR + [illegible] + EGR	7 to 15%	-
			Conv.	AIR + Ox. Cat. or 3-way (open loop) + EGR	-	-
0.41	3.4	0.4	Rotary	[illegible]: Fuel Injection + Thermal Reactor + AIR	2 to 10%	-
			Conv.	[illegible] + 3-way (open loop) + EGR	-	-

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* 1977 Federal emission standard is fuel economy base.

7.3.15. Toyota

7.3.15.1. Systems Under Development

Toyota has several different types of systems under development to meet future standards. These systems are shown in Table Toyota-1, along with an indication of how they will be referred to in this report.

Table Toyota-1

Systems Under Consideration

Toyota System Designation	Description	EPA System Designation
P2	EM+AI(AS)+EGR+CCo	Oxidation Catalyst
P3	EM+AI+EGR+TR+CCo	Thermal reactor plus Oxidation Catalyst
P6	EM+AI+EGR+CCr+CCo	Dual Catalyst
P7	EM+EFI+EGR+CCro	3-Way Catalyst

EM = Engine Modifications, AI = Air Injection, AI(AS) = aspirator, EGR = Exhaust Gas Recirculation, TR = Thermal Reactor, CCo = oxidation catalyst, CCr = reduction catalyst, CCro = 3-way catalyst with feedback system, EFI = Electronic Fuel Injection

Toyota is adapting these systems to three basic engines, described in Table Toyota-2.

Table Toyota-2

Basic Toyota Engines Types

Toyota Designation	Displacement, CID (litres)	Arrangement, Number of Cylinders
2TC	96.9 (1.6)	In-line, 4
20R	133.6 (2.2)	In-line, 4
4M	156.4 (2.6)	In-line, 6

The Toyota engines will be referred to as the 1.6 litre-4, the 2.2 litre-4, and the 2.6 litre-6 in this report.

Oxidation Catalyst Systems

According to Toyota, 60 to 80% of the HC and CO emissions come from the first peak of the emission test for catalyst equipped vehicles. The primary reasons for this are: (1) the engine is still operating under cold start enrichment, thus the HC and CO out of the engine are high, and (2) the catalyst has not reached a high enough temperature to convert HC and CO efficiently. This is shown in Figure Toyota-1.

As can be seen from Figure Toyota-1, the catalyst has not reached its operating temperature of approximately 450° C until about 300 seconds into the test. Note that during the first peak or "hill" of the drive cycle (from zero to about 150 seconds), the catalyst temperature [illegible] than about 200°C, too low for good conversion of the high HC and CO emissions being emitted from the engine.

Toyota has examined several ways to try to improve catalyst "light-off" (bring the catalyst up to temperature quicker). Several approaches were tried.

Thermal reactors were examined, in order to compare them to more conventional exhaust manifolds. The concepts are shown in Table Toyota-3.

Figure Toyota-1

Catalyst Bed Temperature During the LA-4 Driving (IB-C for 49-States)

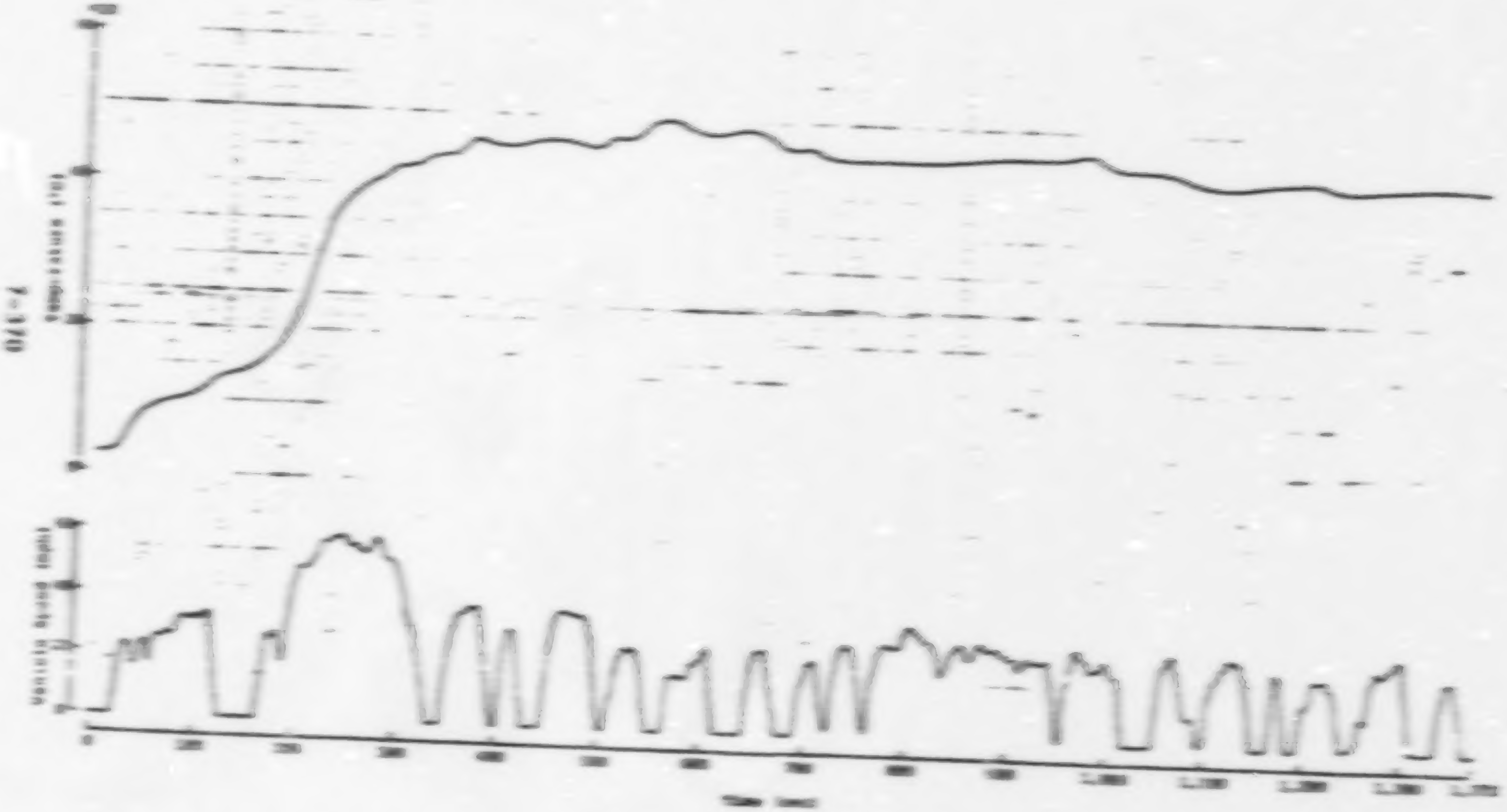


Table Toyota-3

Manifold/Reactor Comparison

Description	Weight (kg)	Volume (litres)	Insulated ?
Exhaust Manifold A	6.3	2	no
Thermal Reactor A	10.0	1.5	yes
Thermal Reactor B	6.8	1.3	yes
Exhaust Manifold B	7.4	2	no

The results of the testing are shown on Figure Toyota-2.

Figure Toyota-2 indicates that the A-type exhaust manifold generally had the best effect on promoting catalyst light-off. However, this does not necessarily mean that the emissions would be the best for this configuration. This is because it is important to know what the emissions were before the catalyst lit off. Toyota ran emission tests on the four configurations. The results are shown in Table Toyota-4.

Table Toyota-4 shows that the B-type thermal reactor was about the same in tailpipe (after CCo) emissions as the A-type exhaust manifold. The reactor-out emissions from the B-type thermal reactor were actually lower than the manifold-out emissions from the A-type exhaust manifold. Toyota chose the A-type manifold for further considerations, because the catalyst inlet temperatures were too high with the B-type thermal reactor, according to Toyota.

The results shown on Table Toyota-4 are interesting because they show that the parameters of thermal reactor/manifold volume, weight, and insulation characteristics are all important. Toyota did not provide enough data on the engine calibrations for all the cases to be able to determine if the emission results shown can be attributed to only the parameters studied. The results do indicate that lightweight, large thermal reactors are more effective than heavier, smaller ones.

Figure Toyota-2
The Effect of Exhaust Manifold and Thermal Reactor
on the Temperature in the Exhaust System (2T-C)

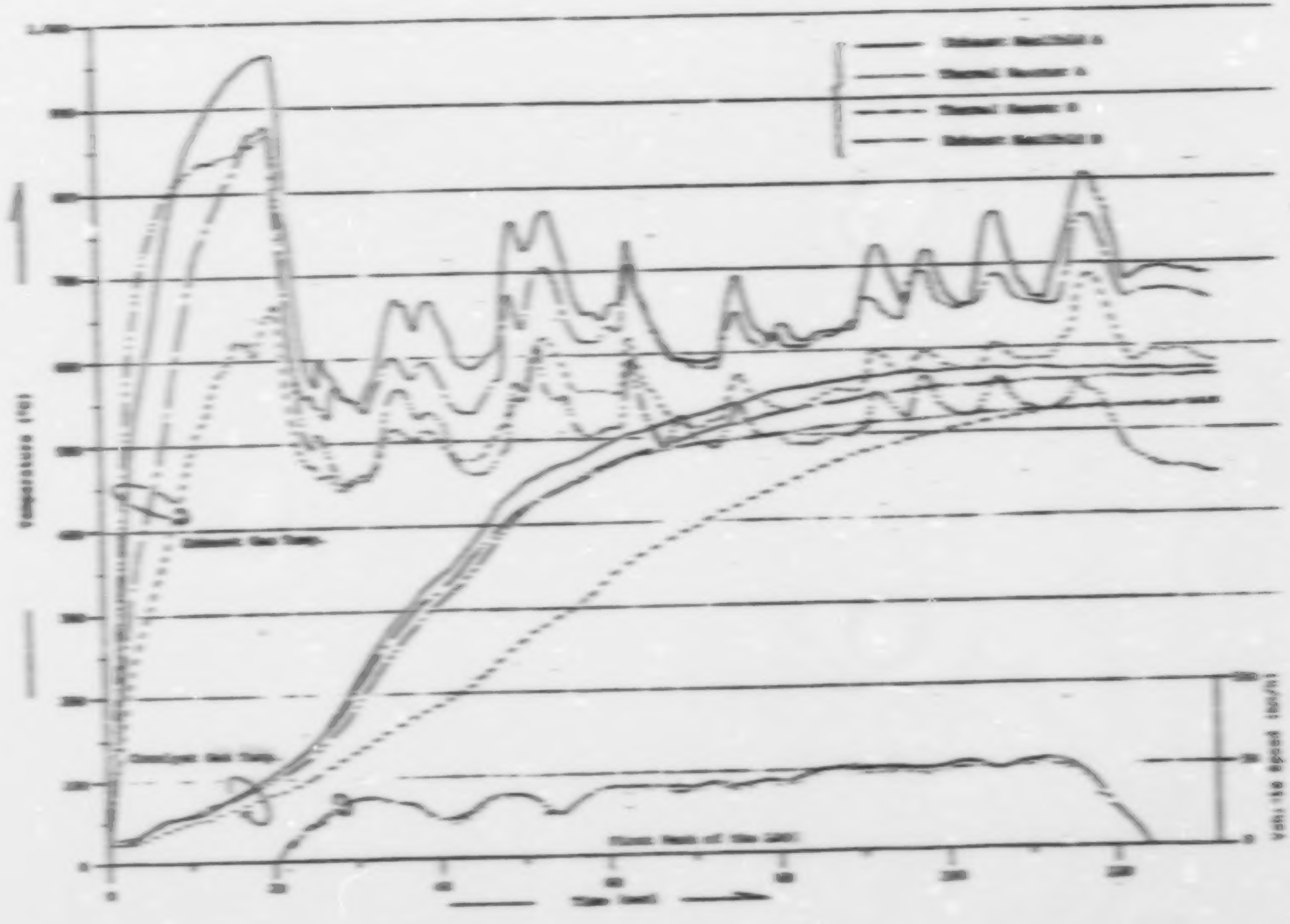


Table Toyota-4

The Effect of Exhaust Manifold and Thermal Reactor on the FTP Emission Test Results

Type		Composite (g/mile)			Cold (g/test)			Hot 1 (g/test)			Hot 2 (g/test)			Fuel Economy (mpg)
		HC	CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx	
Ex. Manifold A	Before CCo	0.570	11.783	0.854	1.317	60.496	5.071	1.026	41.664	2.126	1.788	38.062	3.672	
	After CCo	0.072	1.624	0.846	0.815	15.452	4.854	0.129	1.757	2.146	0.596	1.858	3.683	27.59
Thermal Reactor A	Before CCo	1.861	17.242	0.813	5.673	99.274	4.789	2.538	56.783	1.968	1.618	52.346	3.644	
	After CCo	0.126	2.737	0.754	1.081	36.86	4.347	0.136	1.490	1.894	0.111	1.094	3.318	27.53
Thermal Reactor B	Before CCo	0.445	8.834	0.776	3.344	64.451	4.625	1.137	21.319	1.897	1.337	29.429	3.392	
	After CCo	0.074	2.275	0.728	0.597	26.063	4.157	0.069	2.465	1.861	0.053	3.751	3.148	27.76
Ex. Manifold B	Before CCo	1.026	17.377	1.025	5.729	59.434	6.081	1.558	59.895	2.429	1.511	48.550	4.653	
	After CCo	0.108	1.649	1.042	1.380	28.71	5.842	0.144	2.977	2.578	0.178	1.688	4.835	28.28

Toyota has also looked at the effects of air pump flow rate. Two air pumps were studied, one with 150 cc/rev and one with 220 cc/rev. The emission results are shown on Table Toyota-5 for a vehicle with the 1.6 litre-4 engine, and the effect on catalyst light-off is shown on Figure Toyota-3.

Table Toyota-5

Effect of Air Pump Displacement

Air Pump	Grams Emitted During Bag 1 HC	CO	NOx
150 cc/rev	3.84	65.8	8.97
220 cc/rev	1.13	24.3	9.94

The results shown on Table Toyota-5 imply significant reductions in the HC and CO emissions from the whole test, since Bag 1 includes the cold start portion of the test and accounts for most of the emissions. Reductions of about 40 to 50% in HC and CO could be expected on the whole test, however Toyota did not report the results from the complete test.

Figure Toyota-3 shows why the HC and CO emissions are reduced. The catalyst lights off much faster with the larger air pump. Toyota indicated that because of the NOx increase seen in Bag 1 they would try to offset that by making the air-fuel ratio richer, which will be another reason to use the larger air pump. At light loads under warmed-up conditions, there will be too much air injected which might quench the reactions in the manifold. Toyota plans to divert some of the air pump discharge into the air cleaner during these conditions.

The effect of air pump volume was also examined on a 3000 IW vehicle equipped with a 5-speed manual transmission and the 2.2 litre-4 engine. Hot start tests were run, because the vehicle was apparently O_2 deficient on the second hill of the test. The results are shown in Table Toyota-6.

Figure Toyota-3

The Effect of Air Pump Volume on the Temperature in the Exhaust System (2T-C)

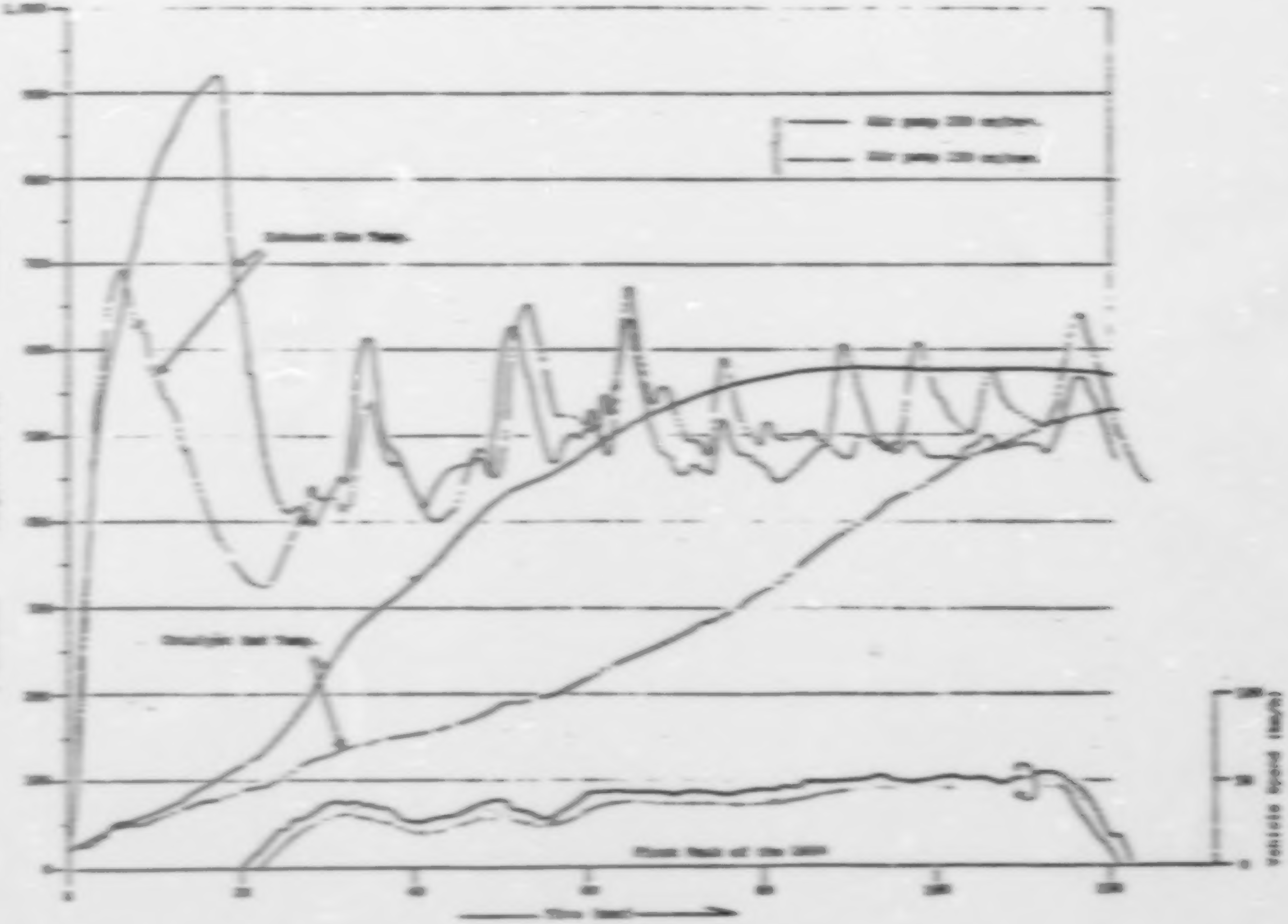


Table Toyota-6

Effect of Air Pump Displacement

Air Pump Displacement	Emissions - Hot Start 1972 FTP HC	CO	NOx
220 cc/rev	0.056	0.812	1.605
375 cc/rev	0.049	0.523	1.576

Table Toyota-6 indicates that the CO benefit for the larger displacement was the greatest, although all three pollutants were lowered with the larger displacement air pump.

Air injection system modifications have also been explored by Toyota. Current systems divert some of the injected air into the air cleaner during deceleration and shifting to eliminate backfiring. A different approach is to inject the air right in front of the catalyst during these modes. The results are shown on Figure Toyota-4.

Figure Toyota-4 shows some CO benefits on the hot start test. The HC impacts are not consistent. The HC emissions went up with an aged catalyst, for example.

A control technique that is similar to increasing the vacuum break was explored. This system was activated by coolant temperature.

As shown on Table Toyota-7 the Bag 1 emissions were reduced for HC and CO but increased for NOx, much in the same manner as the larger air pump. Toyota also reported that the driveability with the increased choke opening was poorer.

Figure Toyota-4

The Effect of Air Injection Before CCO on the HC and CO Emission (2T-C)

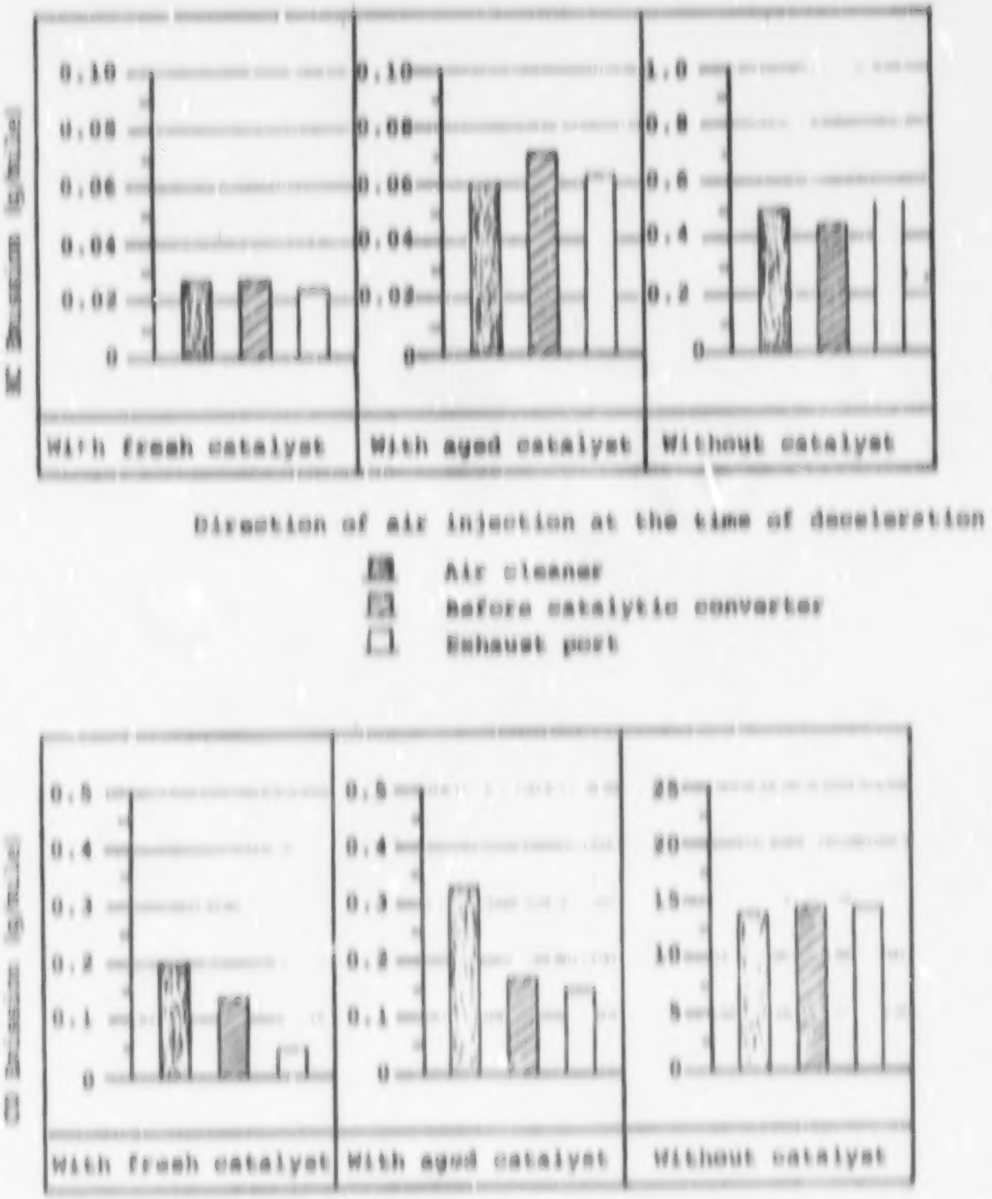


Table Toyota-7

Effect of Choke Opening

System	Grams Emitted During Bag 1 HC	 CO	 NOx
Older system	1.09	43.3	8.7
Newer system	1.13	24.3	9.9

Spark retard and increased idle speed are other techniques to promote fast warm-up. Toyota's results with this approach are shown on Table Toyota-8.

Table Toyota-8

Effects of Idle Speed and Retard

Idle Speed/Retard?	Emissions, 1975 FTP* HC	 CO	 NOx
2400 rpm - no	0.285	1.40	1.65
3400 rpm - yes	0.171	0.971	1.49

---

* assumed to be on 1975 FTP - not specifically stated by Toyota.

Toyota did not quantify the effects of the vacuum spark retard and increased idle speed on fuel economy. Directionally, both approaches tend to make fuel economy poorer. The actual extent of the fuel economy impact will depend on how much these techniques are employed during the test.

Results from tests run to examine the effects of a catalyst volume were also reported. Toyota examined the effect of increasing the catalyst volume on two vehicles. Only the transmissions on the vehicles were specified. The results are shown in Table Toyota-9.

Table Toyota-9

Effect of Catalyst Volume

Catalyst Volume	Vehicle	Emissions - 1975 FTP HC	CO	NOx	MPG_u
2.5 litre	5-speed manual	0.10	2.30	0.60	16.0
3.0 litre	5-speeu manual	0.10	2.03	0.63	16.3
2.5 litre	3-speed auto	0.08	1.92	0.67	16.2
3.0 litre	3-speed auto	0.06	1.64	0.64	17.1

Table Toyota-9 indicates that the larger catalyst volume reduced HC and CO somewhat. The small improvement in fuel economy with the larger catalyst may or may not be a real effect. Toyota did not report details of the calibrations or the number of tests run.

Toyota has experimented with several different ways to improve the warm-up emission performance of their vehicles. Due to the lack of specific vehicle calibration and description, it is not known if the results reported in the Toyota submission, especially the durability vehicles, used any of these technical approaches.

Toyota also reported information about how the spark timing, air-fuel ratio, and EGR rate vary during the emission tests. These results are shown on Figures Toyota-5, Toyota-6, and Toyota-7.

These figures indicate that the air-fuel ratio control used on some current systems permits wide swings in air-fuel ratio ranging from A/F values of 30 or more to A/F values of 10, depending on the mode. This wide range in air-fuel ratio may point to the need for improved fuel metering on future vehicles.

3-Way Catalysts

Toyota considers the 3-way catalyst system to be their best candidate to meet future stringent emission standards. Toyota has an extensive

Figure Toyota-5

EGR Rate During the LA-4 Driving Using
the Computer Simulation Model (3E-C Car for 49-States)

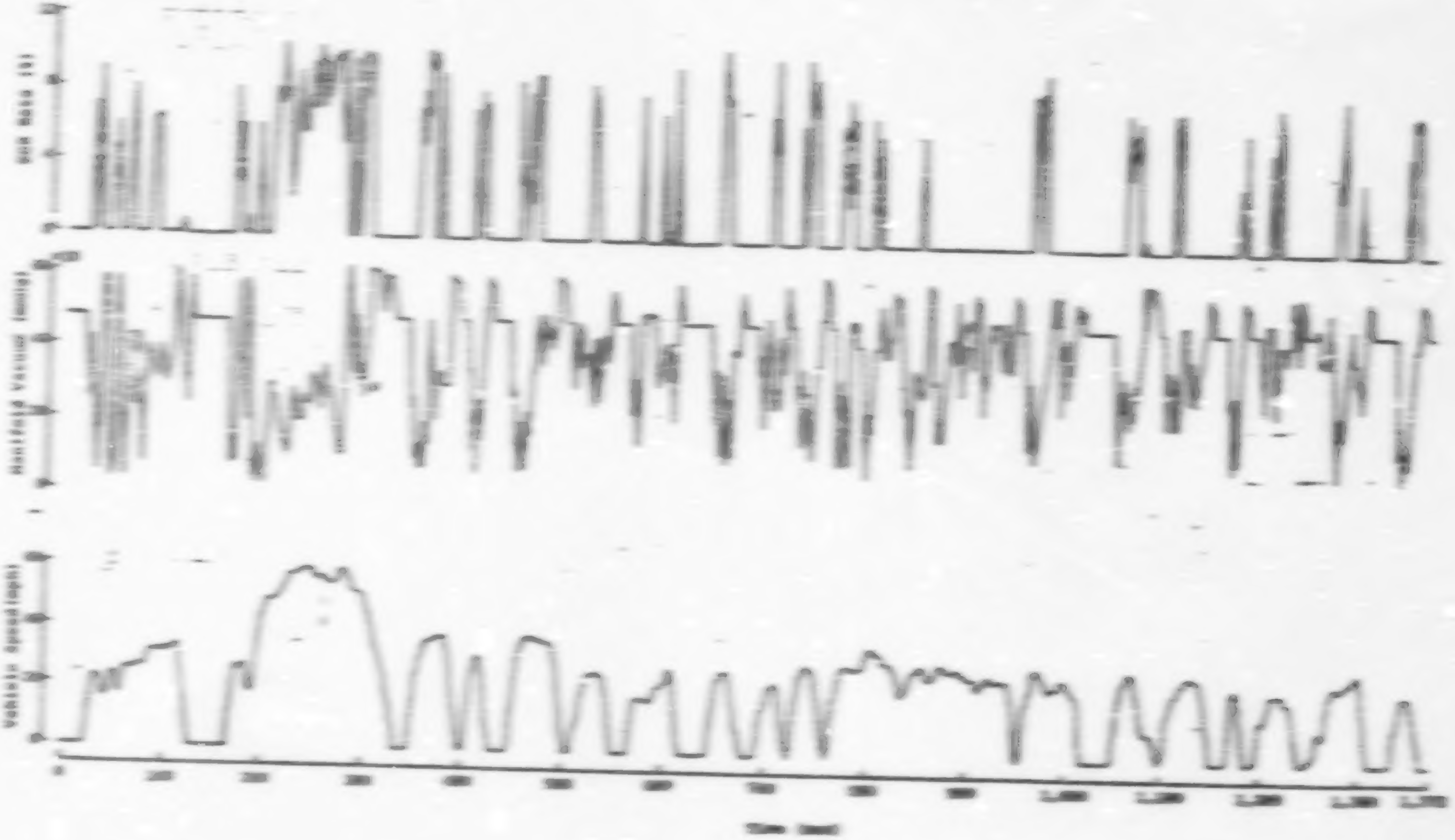


Figure Toyota-6

Spark Timing During the LA-4 Driving (3E-C for 49-States)

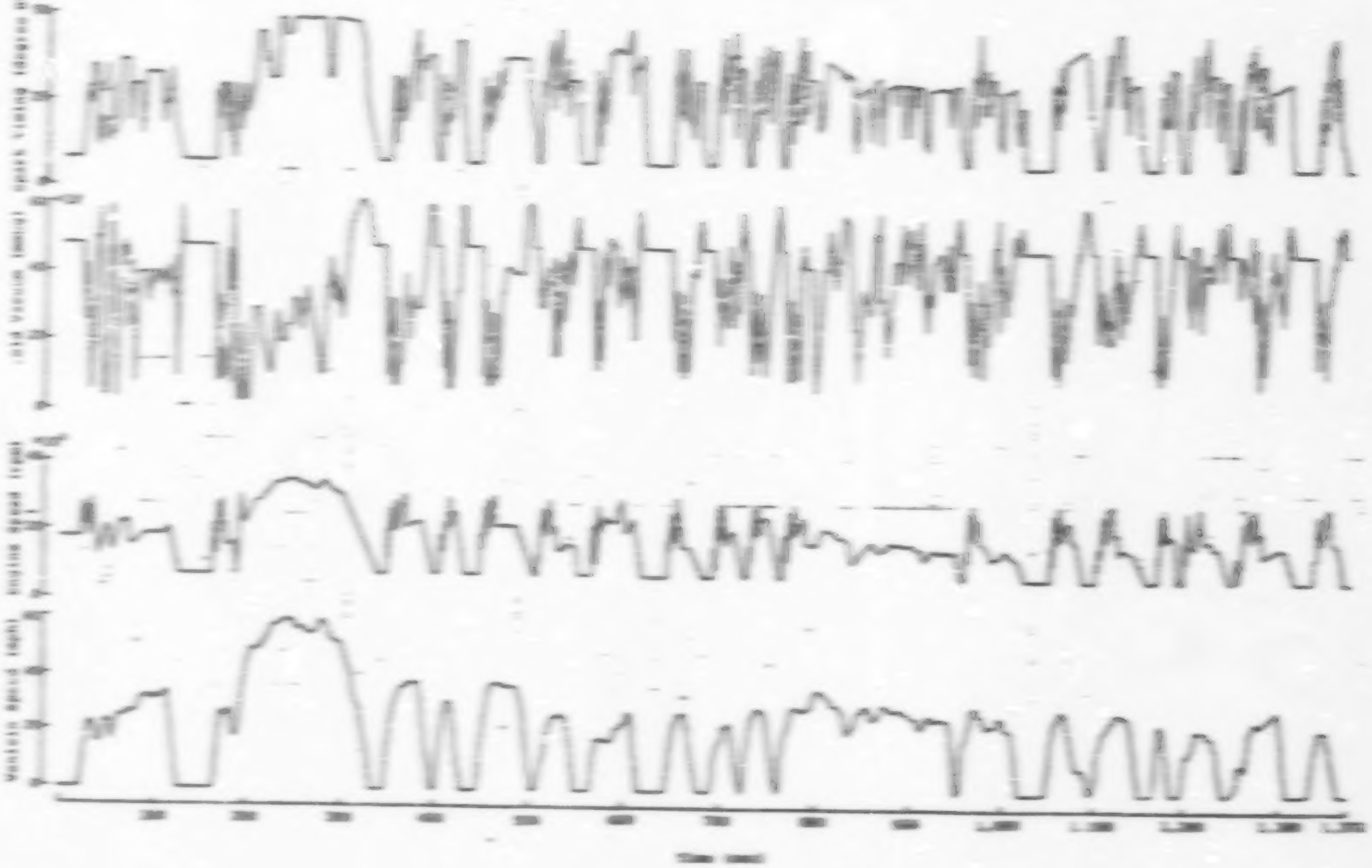
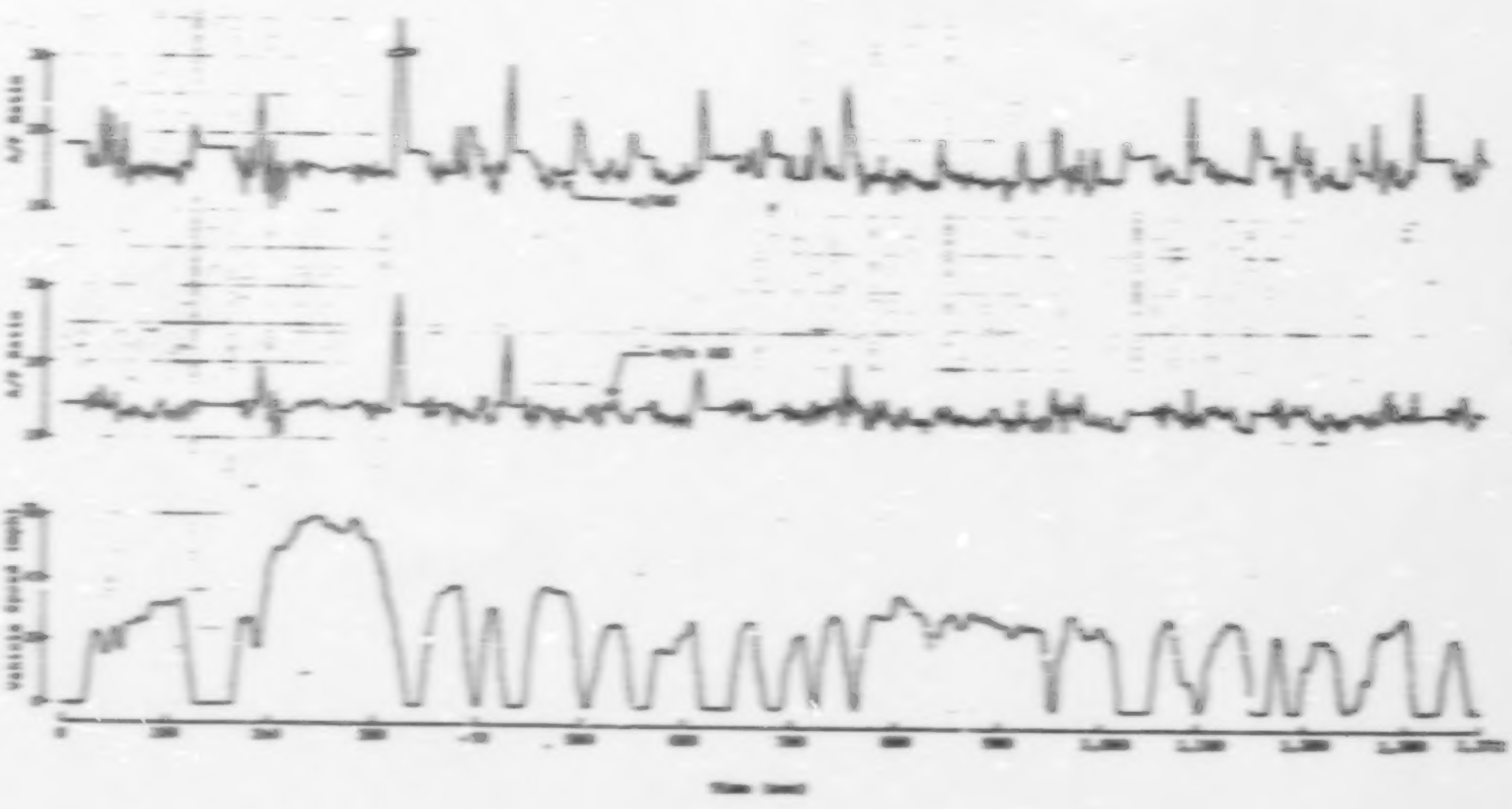


Figure Toyota-7

Air-Fuel Ratio During the LA-4 Driving (CK-C for 49-States)



catalyst screening program underway to evaluate potential 3-way catalyst candidates. The results from a Toyota-developed 3-way catalyst are shown on Figures Toyota-8 and Toyota-9.

No details of the catalyst were provided by Toyota, except to say that this catalyst was a Pt/Rh pelleted catalyst. Catalyst "T" is the best catalyst for which data were reported by Toyota. Efficiency information, read from Figure Toyota-9 is shown on Table Toyota-10.

Table Toyota-10

Parameters from Aged Catalyst "T"

Parameter	Efficiency	Location
HC	Max - 95%	lean 14.8/1 A/F
CO	Max - 98%	lean 14.7/1 A/F
NOx	Max Net - 97%	slightly rich 14.55/1 A/F
HC/NOx crossover	93%	approx. 14.6/1 A/F
CO/NOx crossover	91%	approx. 14.6/1 A/F

The window width at 50% conversion efficiency is about 0.1 A/F units, from approximately 14.5/1 to 14.6/1. This type of aged 3-way catalyst performance is much better than the other 3-way catalysts reported by Toyota, and appears to be competitive with the better 3-way catalysts reported to date. However, differences in the type of catalyst aging tests among those examining 3-way catalysts make absolute comparisons difficult.

Toyota has also examined "stabilized" Ru catalysts, but the results have not been good, indicating that Ru is lost under oxidizing conditions.

Toyota is experimenting with pelleted 3-way catalysts containing Pt/Rh on vehicles. The catalyst loading was not supplied by Toyota. Apparently Toyota is concentrating the development on vehicles with the 2.6 litre-6 engine because that may be the most difficult combination to control.

CATALYST: I FRESH

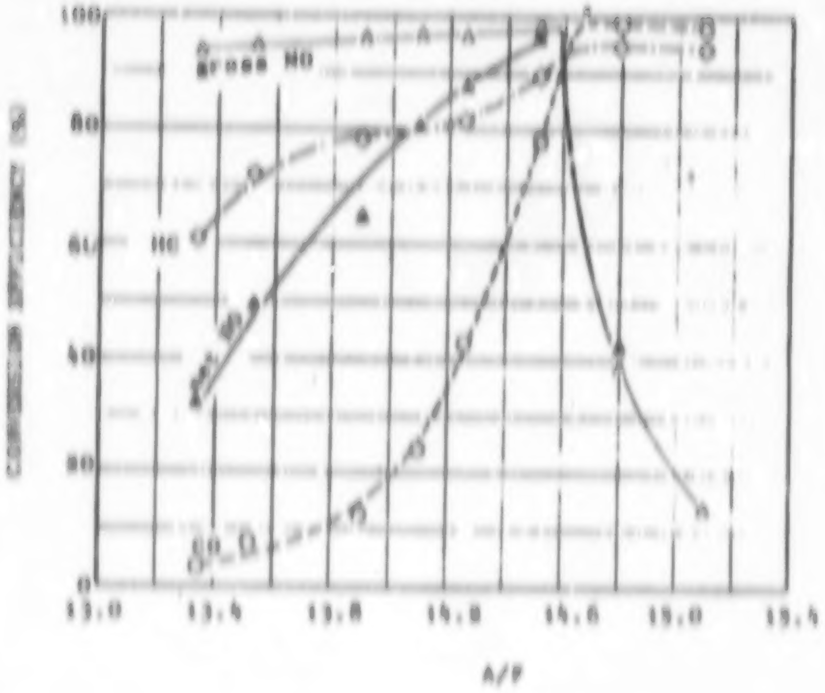


Figure Toyota-8

Catalyst Dynamometer Testing

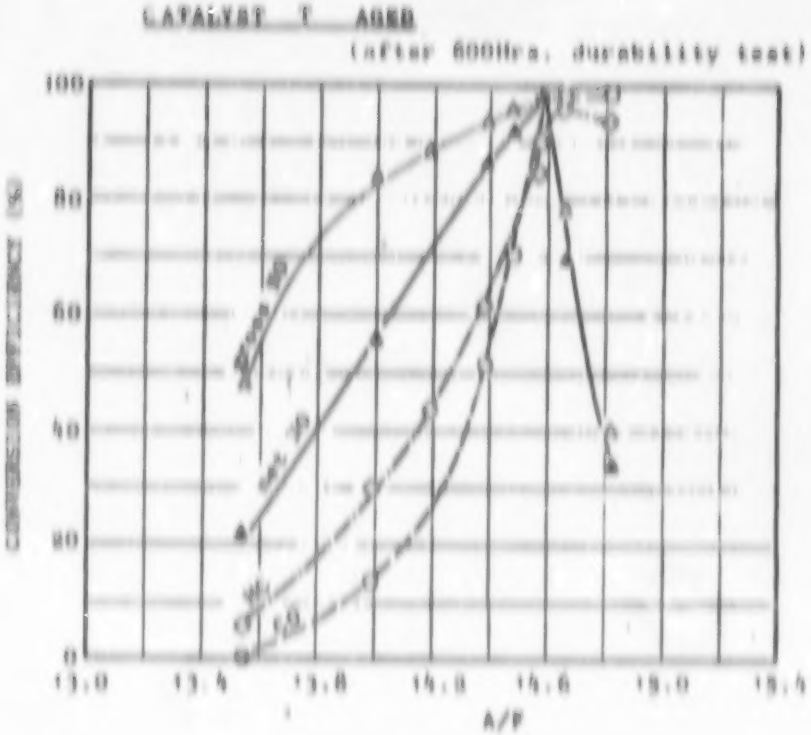


Figure Toyota-9

Catalyst Dynamometer Testing

At the 1.0 NOx level HC and CO have been more difficult to control than NOx, according to Toyota. They examined the influence of fresh versus aged components in the 3-way catalyst system. The testing was conducted on a 3000 IW vehicle, equipped with the 2.6 litre-6 engine and a 4-speed manual transmission. The results are shown on Table Toyota-11.

Table Toyota-11

Effect of Fresh and Aged Components on 3-Way Catalyst System Performance

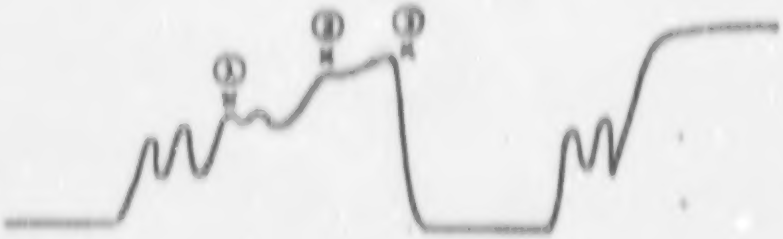
		Emissions - 1975 FTP		
Catalyst Condition	Sensor Condition	HC	CO	NOx
Fresh	Fresh	0.24	2.07	0.42
Fresh	Aged	0.24	1.81	0.44
Aged	Aged	0.41	2.89	0.73

Apparently, the aged catalyst had the biggest effect on emissions. Bag data reported by Toyota indicated that cold-start control was the major problem. To attempt to solve this, Toyoto examined several approaches. The first approach involved the use of a quick warm-up manifold. Temperatures during the test are shown in Figure Toyota-10.

Directionally the quick warm-up manifold should yield lower emissions, because the catalyst is warmed up quicker.

As is the case with oxidation catalyst systems, the influence of catalyst volume is also an important parameter. Toyota studied two catalyst volumes. The results are shown on Table Toyota-12.

		1	2	3
Current type manifold	exhaust gas temperature	460°C	490°C	530°C
	catalyst bed temperature	190°C	240°C	280°C
Warm-up manifold	exhaust gas temperature	530°C	570°C	600°C
	catalyst bed temperature	300°C	360°C	320°C



1st Peak of the LA-4

Figure Toyota-10

Table Toyota-12

Effect of Catalyst Volume

	Emissions - 1975 FTP		
Catalyst Volume	HC	CO	NOx
2.5 litre	0.23	2.20	0.56
3.0 litre	0.24	2.10	0.55

The emissions were not improved very much. The bag data indicate that light-off was not improved with the larger catalyst. It is not known if either catalyst was oxygen deficient on the cold start.

In order to improve the warm-up characteristics, Toyota tried a start catalyst in conjunction with the 2.5 litre catalyst. The start catalyst was a monolithic oxidation catalyst 30 mm (a little more than 1 inch) in length, located directly under the exhaust manifold. The main catalyst was a 3-way catalyst.

The results are shown in Table Toyota-13.

Table Toyota-13

Effect of a Start Catalyst

	Emissions - 1975 FTP			
Catalyst System Type	HC	CO	NOx	Fast Idle Speed
2.5 litre 3-way catalyst	0.22	1.78	0.56	1800 rpm
2.5 litre 3-way catalyst + start catalyst	0.17	2.30	0.24	1800 rpm
2.5 litre 3-way catalyst + start catalyst	0.21	2.76	0.31	1200 rpm

Some HC reduction was observed, but the CO performance was not as good with the start catalyst. The NOx emissions were much lower with the start catalyst. Toyota did not provide enough information to determine the precise reason. The engine calibrations could be different (i.e., richer) with the start catalyst system, or the start catalyst could be using up some of the oxygen making the air-fuel mixture into the main catalyst oxygen deficient. However, these reasons are just conjecture, because Toyota did not provide enough detail to properly explain the results. In general, the use of a start catalyst would not have been expected to have had as great an impact on the NOx emissions from a 3-way catalyst system as are indicated in Table Toyota-13.

Figure Toyota-11 shows the transient temperature performance of the systems described in Table Toyota-13.

Reductions in HC and CO from zero to 20 per cent using air injection on start-up only were reported by Toyota, but no further details were reported and Toyota apparently does not consider the technique to be cost effective.

Dual Catalyst Systems

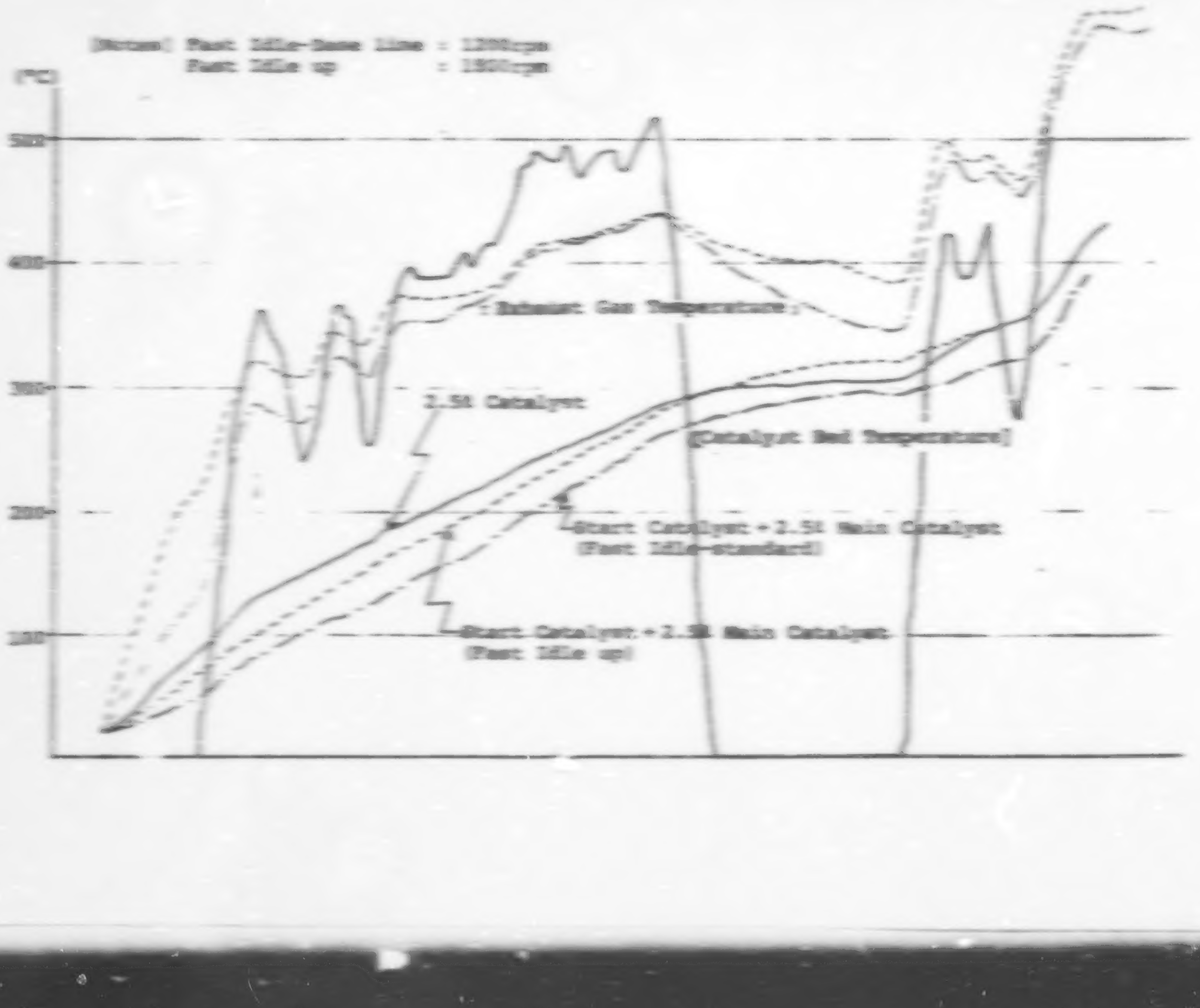
Toyota has worked for several years on dual catalyst systems. Not a great deal of information concerning low mileage system testing was reported by Toyota on this type of system. The majority of the Toyota results with dual catalyst systems are reported in the section on durability testing.

Other Systems

If 0.4 NOx had to be achieved without the use of catalytic control of NOx, Toyota believes that this would require engine specific NOx emissions of 0.5 to 1.0 grams per indicated horsepower-hour under any operating

Figure Toyota-11

Exhaust Gas and Catalyst Bed Temperature
during the 1975 FTP (w/Start Catalyst-4B)



conditions. As far as emissions are concerned, this would be equivalent to an open furnace type of combustion that is below 100 to 150 ppm NOx. Toyota stated:

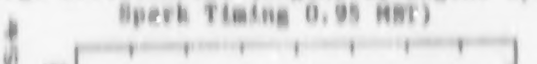
"There may be some approaches for achieving such a low NOx emission in the cylinder of an engine."

According to Toyota, the approach that uses stoichiometric fuel metering plus high EGR rates seems to have the highest potential.

Toyota stated that when EGR is studied, the amount of EGR is not the most important parameter. They feel that the burned gas ratio (BGR) is the important parameter to study. The burned gas in the cylinder is defined by Toyota to be the sum of the residual gases and the EGR in the cylinder. Figure Toyota-12 shows the relationship among BGR, EGR, NOx, ISFC, and IMEP as a function of manifold pressure.

Figure Toyota-12

Effect of EGR and BGR on NOx, IMEP and ISFC under Various Charge Efficiencies (Engine B, Engine Speed 2000 rpm, Spark Timing 0.95 MBT)



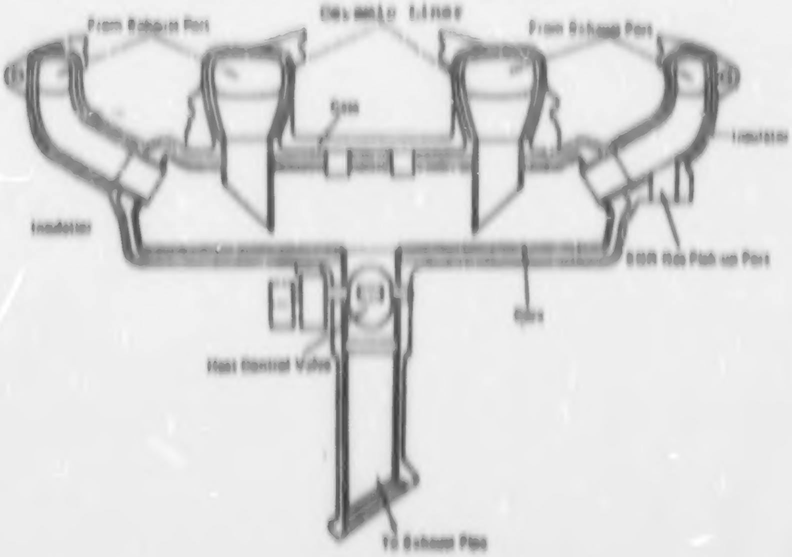
Toyota indicated that Figure Toyota-12 shows that EGR as a constant proportion of intake air (proportional EGR) is not the best way to control NOx. The values of constant EGR in Figure Toyota-12 (assumed to be the dashed lines in the lower portion of the figure) do show a more direct relationship to ISNOx, for all manifold pressures.

It appears that EGR values of 25% or more may be needed to achieve the 0.5 to 1.0 ISNOx values. Toyota did not indicate how this could be achieved in a practical system. It might be accomplished by having the EGR rate increase as manifold pressure increases, which can be inferred from Figure Toyota-12.

Toyota uses some heat conservation techniques on some of their current vehicles. Port liners and thermal reactors are two examples. A cast case, stainless steel outer core, stainless steel inner core thermal reactor was used on the 1976 Land Cruiser model. Temperatures increased by 200°F resulting in a sharp HC reduction, but it is expensive and difficult to produce, according to Toyota. Toyota also used a ceramic liner cast on the branches of a thermal reactor. A schematic of this system is shown on Figure Toyota-13.

Figure Toyota-13

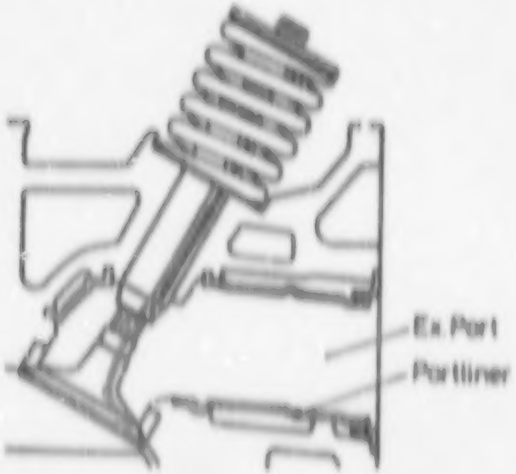
Thermal Reactor Configuration


From Exhaust Port
Ceramic Liner
From Exhaust Port
Case
Insulator
Insulator
EGR Gas Pick up Port
Core
Heat Control Valve
To Exhaust Pipe

Toyota also reported that they are working on ceramic port liners. Current ones are metal. A schematic of the port liner is shown in Figure Toyota-14. No details were presented.

Figure Toyota-14

Exhaust Port Liner



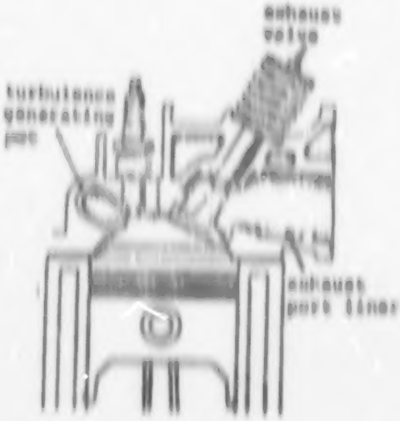
The use of ceramics may also be extended to piston heads and cylinder liners. Previous attempts to reduce HC in the quench layer by use of stainless steel were not effective and caused a torque loss and spark knocking.

Other Engines

Toyota has two engines under development that utilize a small Turbulence Generating Pot (TGP) in the combustion chamber to increase turbulence and thereby extend the lean limit. The TGP is a small alloy steel cavity located adjacent to the spark plug. The spark plug tip is located at the mouth of the cavity and after the mixture is ignited the outrushing gas from the TGP greatly increases the combustion chamber turbulence. Toyota has two versions of this concept, the TTC-V and TTC-L. The TTC-V is similar in principle to the Honda CVCC. It has an intake valve located in the TGP which is fed a richer air-fuel ratio than the main chamber. Toyota reported a limited amount of development work on the TTC-V. This was in the area of engine modifications and heat conservation measures. These were intended to increase turbulence and conserve exhaust gas heat and thereby allow further enleanment to better optimize emissions, fuel economy, and driveability. These modifications were: a cast in place exhaust port liner; increased compression ratio (from 8.0 to 8.3); added squish area in combustion chamber; and insulated exhaust manifold. Toyota did not present U.S. emission test results for a system incorporating these changes.

The second version of the TGP concept is the TTC-L. Shown in Figure Toyota-15, the TTC-L is a simpler engine. This engine has the TGP but does not have an intake valve located in it. Thus the TGP receives the same air-fuel ratio as the rest of the chamber. Toyota reported that development work was proceeding on the TTC-L in the following areas: improved ignition system; modified TGP; investigation of main chamber configuration; improvement of mixture distribution; and addition of an oxidation catalyst. No U.S. emission test results were provided on this work.

Figure Toyota-15
TTC-L Engine



Fuel Economy

Toyota reported fuel economy results comparing some developmental systems targeted toward stringent emission standards to some current (model year 1977) vehicles. Figure Toyota-16 shows the results for manual transmission vehicles and Figure Toyota-17 shows the results for vehicles equipped with automatic transmissions. Note that these are steady state fuel economy results.

The prototype vehicles in Figures Toyota-16 and Toyota-17 are Corona vehicles, targeted for 0.41 HC, 3.4 CO, 1.0 NOx. In general, the prototype vehicles targeted toward much more stringent standards show much improved fuel economy over the 1977 Corona models, although some axle ratio differences are apparent.

These results are also important because they show that the Corona prototype vehicles have better fuel economy than some of the Corolla and Celica models for 1977. The Corona vehicle is typically a 3000 IW vehicle, whereas the Corolla is generally 2250 IW and the Celica is 2750 IW. Thus, the prototype vehicles returned better fuel economy on this test than some current lighter weight Toyota vehicles.

The only vehicle that significantly bettered the prototype vehicles was the 1977 3 K-C Corolla. The 71 CID 3 K-C engine was dropped from the U.S. market for 1975. It was re-introduced in 1977 as part of a fuel economy package. Toyota claims that more stringent standards will cause this engine to be dropped again. Toyota presented no data on any system optimization of this engine for future standards, so the reasons behind their claim cannot be examined. The certification results from the 3 K-C do not appear to indicate major problems.

These fuel economy results indicate that Toyota has the potential to improve fuel economy and emission control over their current systems.

Figure Toyota-16

Comparison of Fuel Economy of 1977 and Prototype (0.41-3.4-1.0) Model Steady State Drive Pattern (2)

[Manual Transmission] (km/ℓ)

Vehicle / Ax. ratio / Vehicle Speed (mph)	BT-PF*-18 3.909	BT-PF*-18 3.727	'77 3K-C Corolla (5M/T) 4.100	'77 3K-C Corolla (4M/T) 3.909	'77 2T-C Corolla (5M/T) 4.300	'77 2T-C Corolla (4M/T) 4.100	'77 Celica (5M/T) 3.583	'77 Corona (4M/T) 3.583
30	15.5	16.7					(5th) 12.3	13.1
35			(5th) 18.9	18.5	(5th) 16.1	(5th) 15.6		12.9
40	14.4	15.1	17.1	17.1	14.7	14.7	12.6	12.9
50	13.2	13.6	15.9	16.1	13.1	13.2	12.3	12.1
60	11.8	12.3	13.4	13.7	12.0	12.1	11.0	11.6
70	10.4	10.9	11.0	11.3	10.3	10.6	10.1	9.4
80			9.3				8.7	8.3

* Prototype (0.41-3.4-1.0)

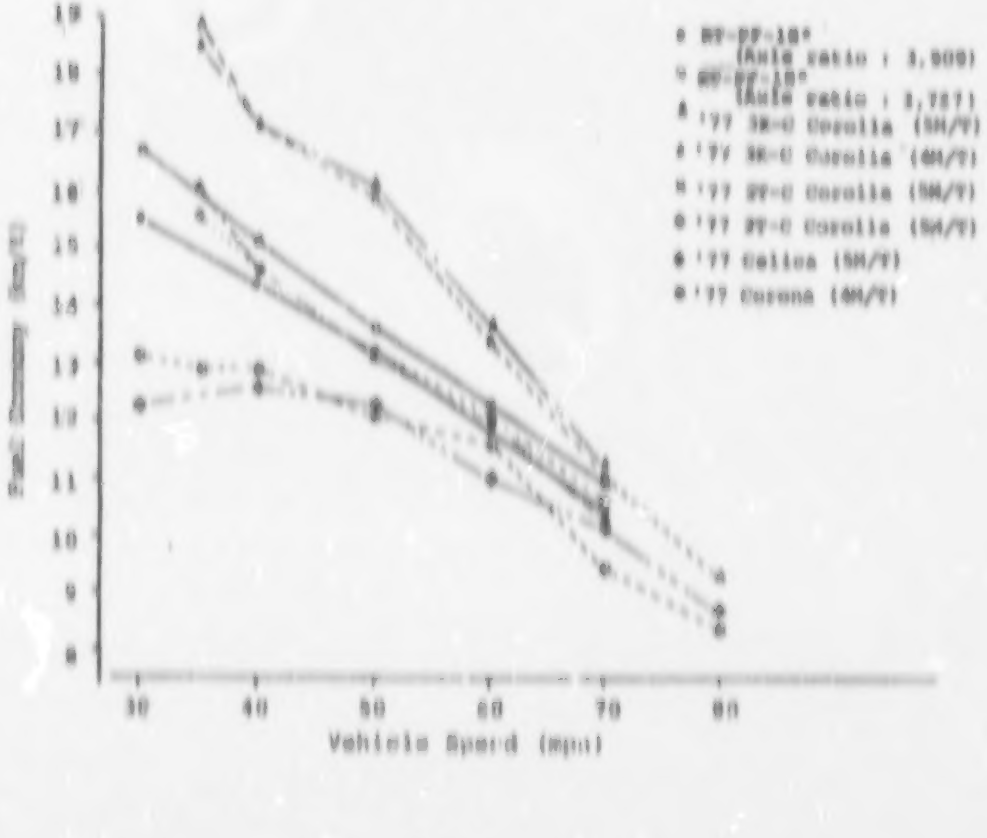


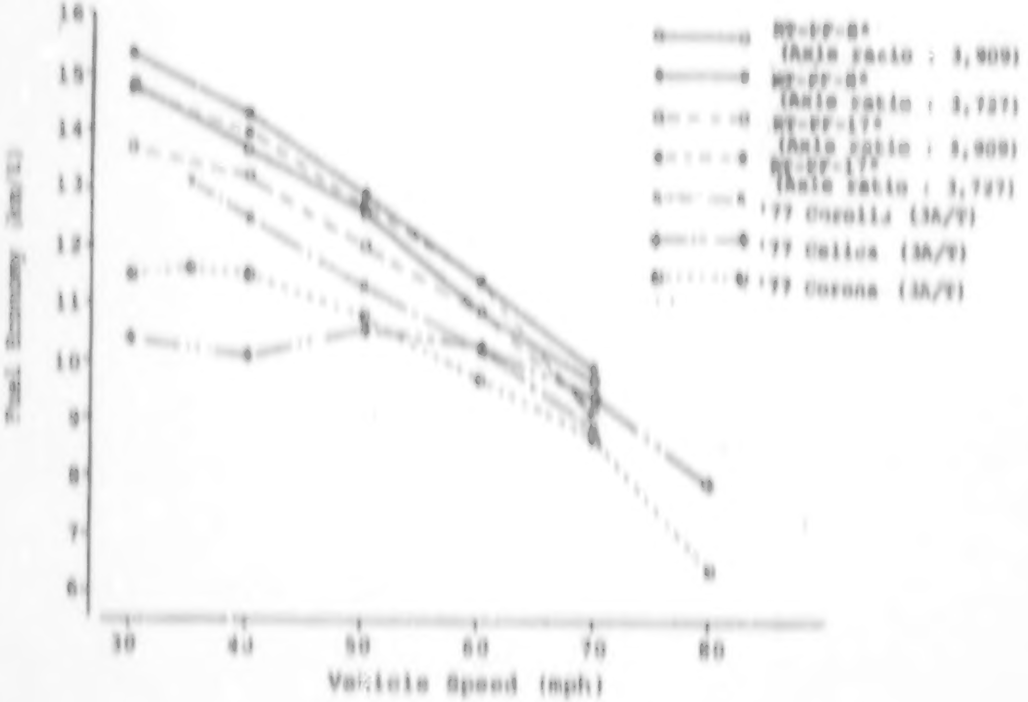
Figure Toyota-17

Comparison of Fuel Economy of 1977 and Prototype (0.41-3.4-1.0) Model on Steady State Drive Pattern (1)

(Automatic Transmission) (km/ℓ)

Vehicle / Axle ratio / Vehicle speed (mph)	RT-FF a -8	RT-FF a -8	RT-FF a -17	RT-FF a -17	'77 Corolla (3A/T)	'77 Celica (3A/T)	'77 Corona (3A/T)
	3.909	3.727	3.909	3.727	4.100	3.727	3.583
30	14.9	15.3	13.7	14.7		10.4	11.5
35					13.1		11.6
40	13.7	14.3	13.2	14.0	12.5	10.1	11.5
50	12.6	12.8	12.0	12.7	11.3	10.6	10.8
60	10.9	11.4	10.0	11.4	10.2	10.3	9.7
70	9.7	9.9	9.3	9.1	8.9	9.4	8.7
80						7.9	6.4

*Prototype (0.41-3.4-1.0)



7.3.15.2. Systems to be Used at Various Emission Standards

1.5 HC, 15 CO, 2.0 NOx

For these emission levels, Toyota would apparently keep the same systems as the ones in current (1977) use. One exception is the 1.6 litre-4 engine family. This would be modified to incorporate higher compression ratio, a different camshaft, a smaller intake port diameter, and a 1.5 litre catalyst. This is done to improve fuel economy, driveability, and engine performance, according to Toyota.

0.41 HC, 9 CO, 1.5 NOx

Toyota reported that they would have no problems technologically in meeting this standard. Their vehicles could comply on a Federal basis, according to Toyota. If the methane exclusion would not be permitted for 0.41 HC, then Toyota would adopt double wall exhaust pipes to improve the HC performance. Toyota did not indicate if they would include this potential improvement for increased HC emission control, which might permit a better fuel economy calibration, if the methane credit was given.

Toyota's major problems with this standard are cost and lead time. Lead time is just about gone for 1978, according to Toyota, due primarily to the need to get air pumps and catalysts from vendors.

0.41 HC, 3.4 CO, 1.0 NOx

Toyota has run evaluation tests on their oxidation catalyst and thermal reactor plus oxidation catalyst systems targeted toward this level. Some results are shown in Table Toyota-14. The vehicle is a 2750 IW Corona with the 2.2 litre-4 engine.

Table Toyota-14

Potential 0.41 HC, 3.4 CO, 1.0 NOx Systems

System	Catalyst Input Emissions - 1975 FTP		
	HC	CO	NOx
Oxidation catalyst	0.749	11.08	1.2
Thermal reactor plus oxidation catalyst	0.583	11.09	1.28

	Tailpipe Emissions - 1975 FTP		
	HC	CO	NOx
Oxidation catalyst	0.219	3.95	1.10
Thermal reactor plus oxidation catalyst	0.208	4.85	1.13

Toyota attributed the better CO performance of the oxidation catalyst system to quicker warm-up. The NOx performance shown in Table Toyota-14 does not appear to be sufficient for a 1.0 NOx standard for either system.

Although Toyota has done much work with oxidation catalyst and thermal reactor plus oxidation catalyst systems targeted for 1.0 NOx, they now are concentrating on the 3-way catalyst approach for 0.41 HC, 3.4 CO, 1.0 NOx.

A system incorporating electronic fuel injection is receiving the most attention although Toyota did indicate that they are working on a carbureted back-up system, even though the carbureted package is considered by Toyota to be less promising from an emission control standpoint.

0.41 HC, 3.4 CO, 0.4 NOx

Toyota has investigated three systems for this emission standard.

They reported that they were able to attain the required emission levels at low mileage with the thermal reactor plus oxidation catalyst system, but the durability is not considered adequate by Toyota. The fuel economy and driveability performance of this system is also not good, according to Toyota.

Toyota's experiments with dual catalyst systems have indicated a lack of durability for the NOx catalyst. Ammonia formation and warm-up characteristics also remain a problem. Toyota is concentrating their efforts in the area of NOx catalyst development now. System work will await further catalyst improvements.

Toyota will concentrate their efforts toward meeting 0.41 HC, 3.4 CO, 0.4 NOx on 3-way catalyst systems.

7.3.15.3. Durability Testing

Toyota's plans for durability testing are shown on Figure Toyota-18.

Figure Toyota-18 indicates that Toyota has completed durability testing on some systems. The most current durability testing is targeted toward 0.41 HC, 3.4 CO, 1.5 or 1.0 NOx, according to Figure Toyota-18, not 0.41 HC, 3.4 CO, 0.4 NOx.

Toyota reported durability test data from 23 vehicles. The 3-way catalyst and dual catalyst systems are of the most importance and are reported in Table Toyota-15.

Table Toyota-15

Emissions Results from Prototype Durability Vehicles

VIN	System	Highest Mileage Reported	Emissions		
			HC	CO	NOx
TA-159	3-way	30,000	0.75	5.27	0.64
TA-159*	3-way	30,000	1.01	7.42	0.41
TA-158	3-way	28,100	0.28	1.91	0.90
TA-205	3-way	18,800	0.46	3.63	0.97
TA-204	3-way	20,000	0.39	3.70	0.60
TA-212	3-way	18,600	0.57	4.18	0.38
TA-212*	3-way	18,600	0.48	3.26	0.37
TA-213	3-way	31,100	0.60	3.97	1.00
TA-213*	3-way	31,100	0.65	4.62	0.37
MX-PF-302	3-way	15,000	0.41	2.23	0.62
MX-PF-10	3-way	15,900	0.40	2.28	0.78
TA-202	Dual	18,800	0.47	3.30	2.01
TA-208*	Dual	18,800	0.43	3.05	1.25
TA-201	Dual	70,000	0.48	2.86	0.70
TA-201*	Dual	30,000	0.40	1.90	0.55
TA-207	Dual	20,000	0.57	2.48	0.92
TA-215	Dual	18,606	0.20	1.06	1.42
TA-216	Dual	18,600	0.27	0.82	1.75

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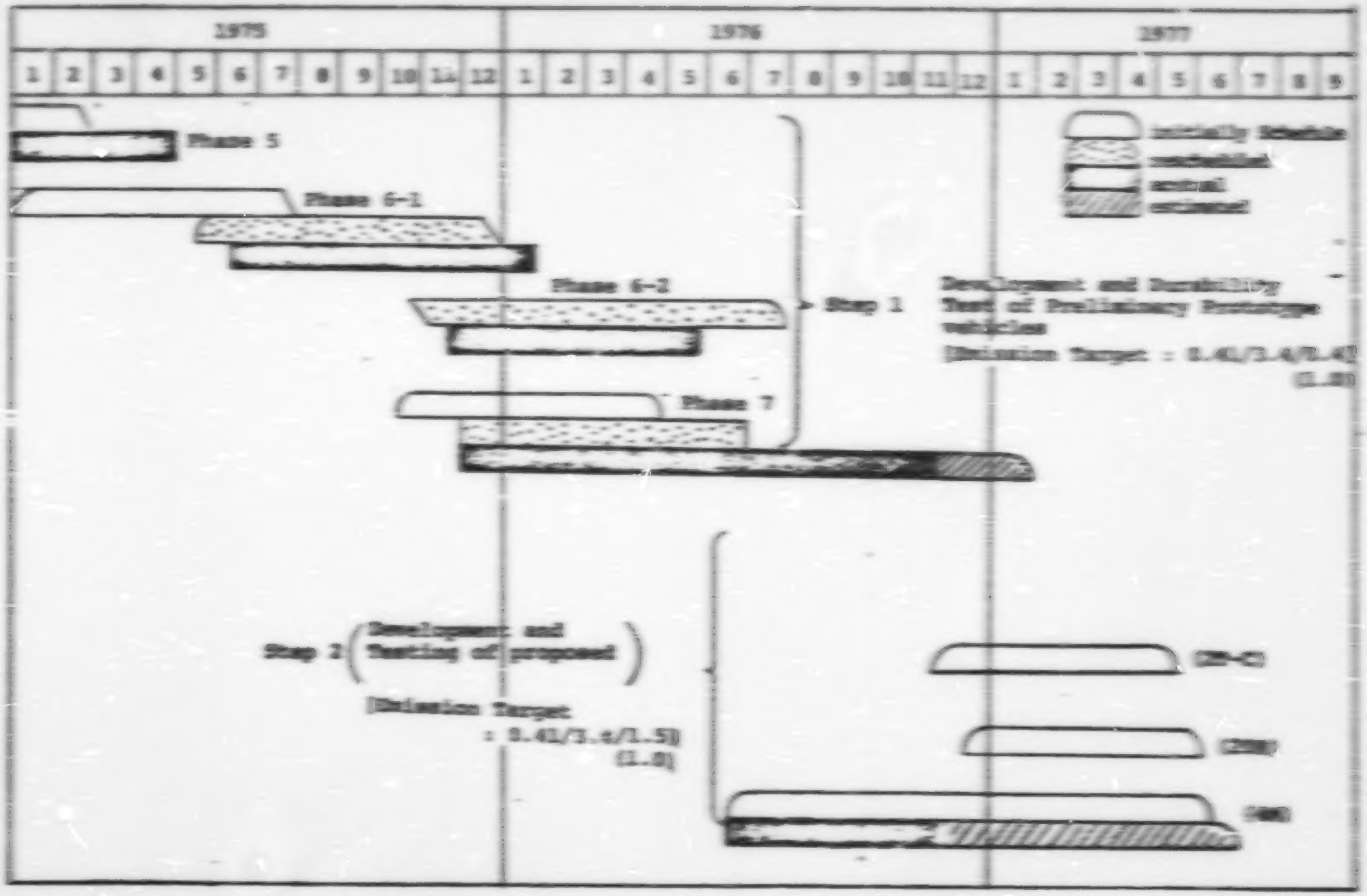
* After maintenance

Figure Toyota-18

1977 thru 1981 Test Program Status



None of these prototype vehicles completed 50,000 miles of durability testing. Typical of developmental durability testing, components were replaced when necessary and recalibrations were performed during mileage accumulation. No details of the systems or the catalysts were provided by Toyota, so it is not known what types systems or catalysts (if any) were used on these vehicles. Based on the results in Table Toyota-15, it appears that Toyota has more difficulty controlling HC and CO than NOx with 3-way catalyst systems at the 0.41 HC, 3.4 CO, 1.0 NOx levels.

7.3.15.4. Progress and Problems

Toyota has made some progress in developing systems to promote quick warm-up of catalytically controlled emission control systems. They have also made progress in identifying the basic system type that will be investigated in an attempt to meet future emission standards. At least one promising catalyst has been identified in Toyota's catalyst evaluation process.

The lack of acceptable emission control from prototype vehicles at high mileage appears to be one of Toyota's major problems. Toyota reported problems with cold-start emission control, cost, and manufacturability with several of their advanced concepts.

Toyota has apparently not combined and tested all of the components of the emission control system, including, for example, the most promising catalysts and cold-start control approaches. Therefore, this lack of information about the capability of more advanced systems is a problem in estimating Toyota's capability to comply with future emission standards. The advanced control techniques under investigation by Toyota do show promise, however.

7.3.16. Volkswagen (VW)

7.3.16.1. Systems Under Development

Oxidation Catalysts

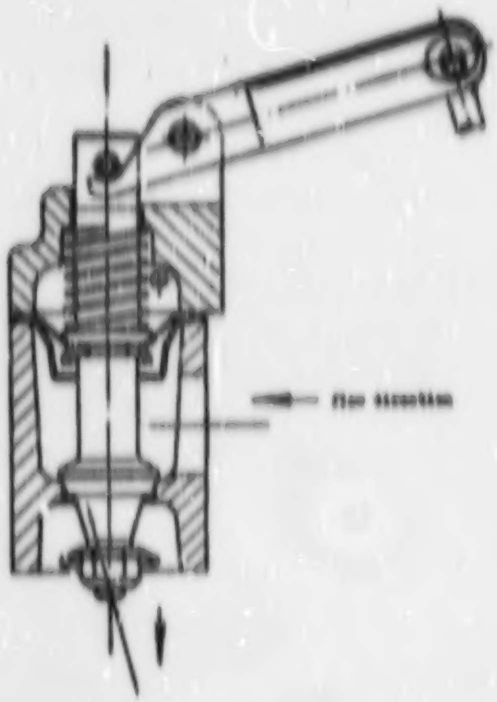
Volkswagen reported continued research on their improved oxidation catalyst which was just reported to EPA last year. This new improved oxidation catalyst is a 74 cu in. Johnson Matthey monolithic catalyst with a specified Pt/Rh ratio ranging from mine mix (19/1) to the (5/1) ratio employed on the Volvo vehicles. While this level of rhodium is unusual for an oxidation catalysts, the range is too broad and might allow VW to manipulate the Pt/Rh loading in production to be significantly different from that in certification, with potential emission differences.

Because of this broad Pt/Rh range and the use of rhodium in VW's oxidation catalyst, VW is able to obtain some NOx control with their oxidation catalyst. In response to a question from EPA, VW admitted that it was their intention to use their oxidation catalyst to control NOx during rich excursion from normal lean fuel metering operation, i.e. power enrichment.

In addition to attaining NOx control, VW has agressively sought to reduce their oxidation catalyst's size and now have reduced the catalyst length from six inches down to three inches. Last year status indicated that VW was experimenting with oxidation catalysts lengths as short as one inch long. These one inch long oxidation catalysts showed power poor NOx conversion efficiencies, but only slightly reduced HC conversion efficiency. Last year's data indicates that VW's three inch long catalyst may not be the smallest optimum length yet in light of VW's increase of cell density from 200 to 300 per square inch.

For 1978 VW has introduced a mechanically actuated EGR valve on its carbureted, water cooled, 49 state models and on its air cooled 49 state and California models. The valve is shown in Figure VW-1. All of these systems provide a cooled exhaust gas input to the valve, which should provide additional NOx control. The valve is actuated by a mechanical linkage which is connected to the throttle. VW claims that this system provides EGR at a rate proportional to intake air flow. As with most EGR systems, the flow is cut off at idle and wide open throttle.

Figure VW-1
Mechanical EGR Valve



Included with the VW mechanically actuated EGR description there was mentioned an EGR filter. The VW submission was not clear whether the EGR filter was applicable to both catalyst (unleaded fuel) and non-catalyst (leaded fuel) vehicles. The VW Part I application indicates the EGR filter is used only with the non-catalyst vehicles and on the catalyst vehicle it is used as an EGR cooler by removing the filtration element from the filter housing.

What is significant about this filter is not its application to gasoline powered vehicles, but the potential application of this type of technology to Diesel powered vehicles. VW indicates in their Part I application for certification that no maintenance is required on the EGR filter for the gasoline engine for the entirety of the 50,000 durability testing. This indicates that an EGR filter is now a reality for gasoline engines. This type of technology might be able to be applied to Diesel powered vehicles which may need EGR to achieve low NOx levels.

Figures VW-2 and VW-3 indicate the extent of reactive HC reduction attainable from an oxidation catalyst. Those figures provide an example of how difficult it is for an oxidation catalyst to reduce non-reactive hydrocarbons.

3-Way Catalyst Systems

VW has previously reported work on closed loop, modulated air injection for 3-way catalyst systems. They now report that this approach has been deemphasized in favor of the more conventional modulation of fuel metering approach. This decision was based upon the probable fuel economy advantages of the latter approach. The fuel metering systems will include closed loop controlled fuel injection (Bosch L-Jetronic and K-Jetronic) and closed loop carburetion.

VW indicates that 3-way catalyst systems will be used for emission levels of 0.41 HC, 3.4 CO, 1.0 NOx and below. VW also indicated that they have obtained low mileage results with a 3-way catalyst plus EGR system, but report they are not confident in this system's durability for production.

VW reported data that appeared to show that a temperature related correction factor should be applied to the oxygen sensor signal to achieve optimal conversion of HC, CO, and NOx. See Figure VW-4. On the

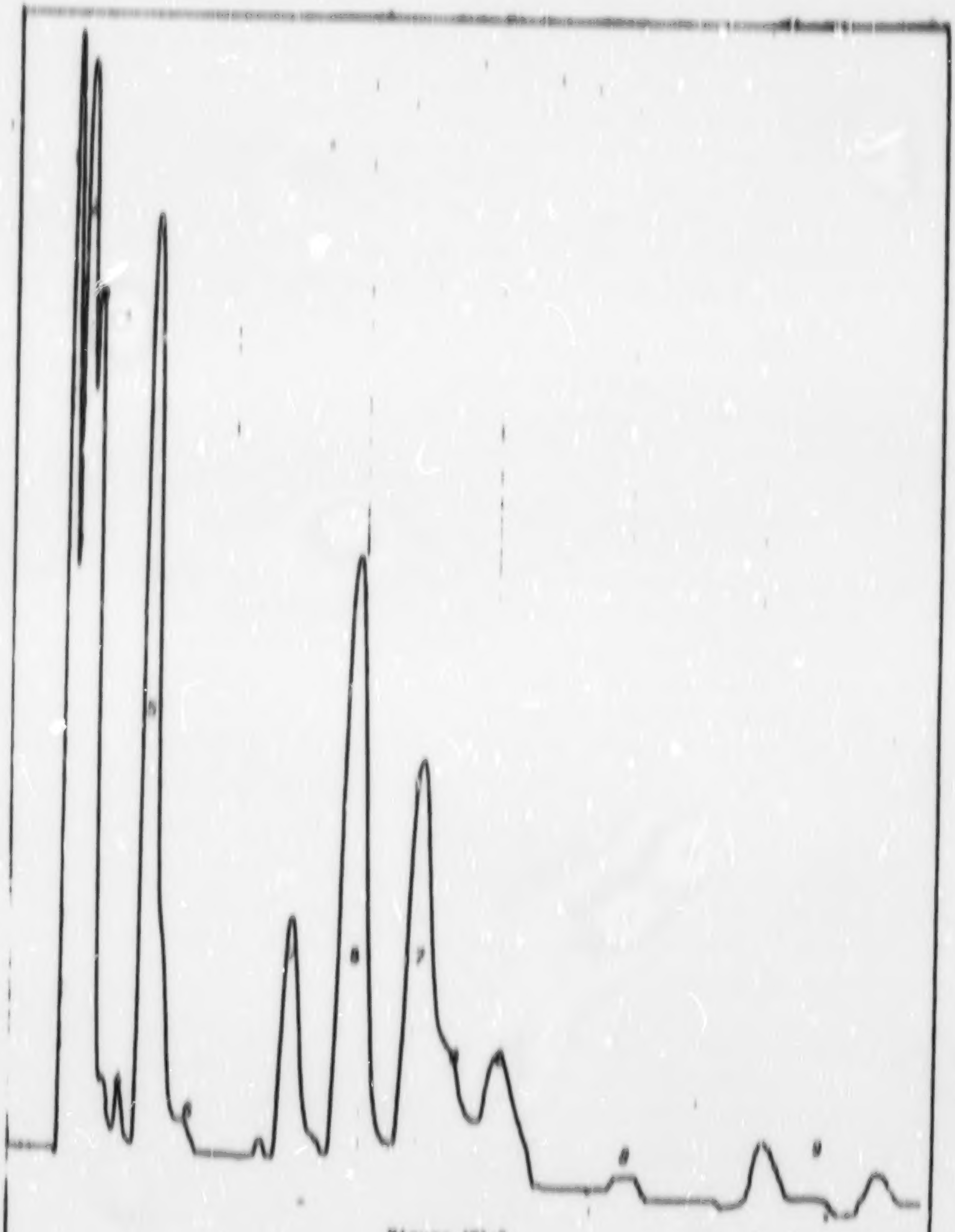


Figure VW-2

Exhaust emission chromatogram at the inlet of the catalyst (column II)

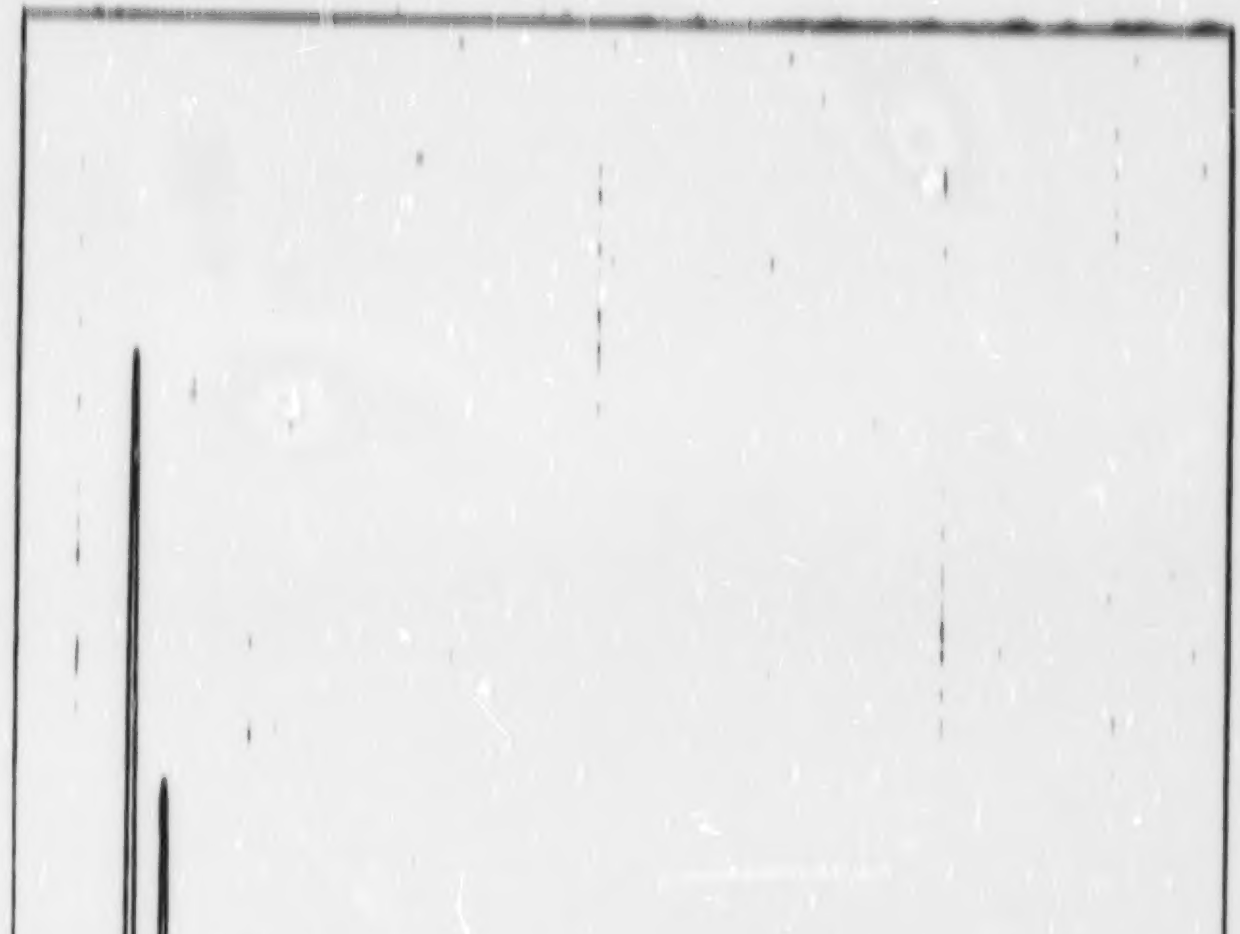
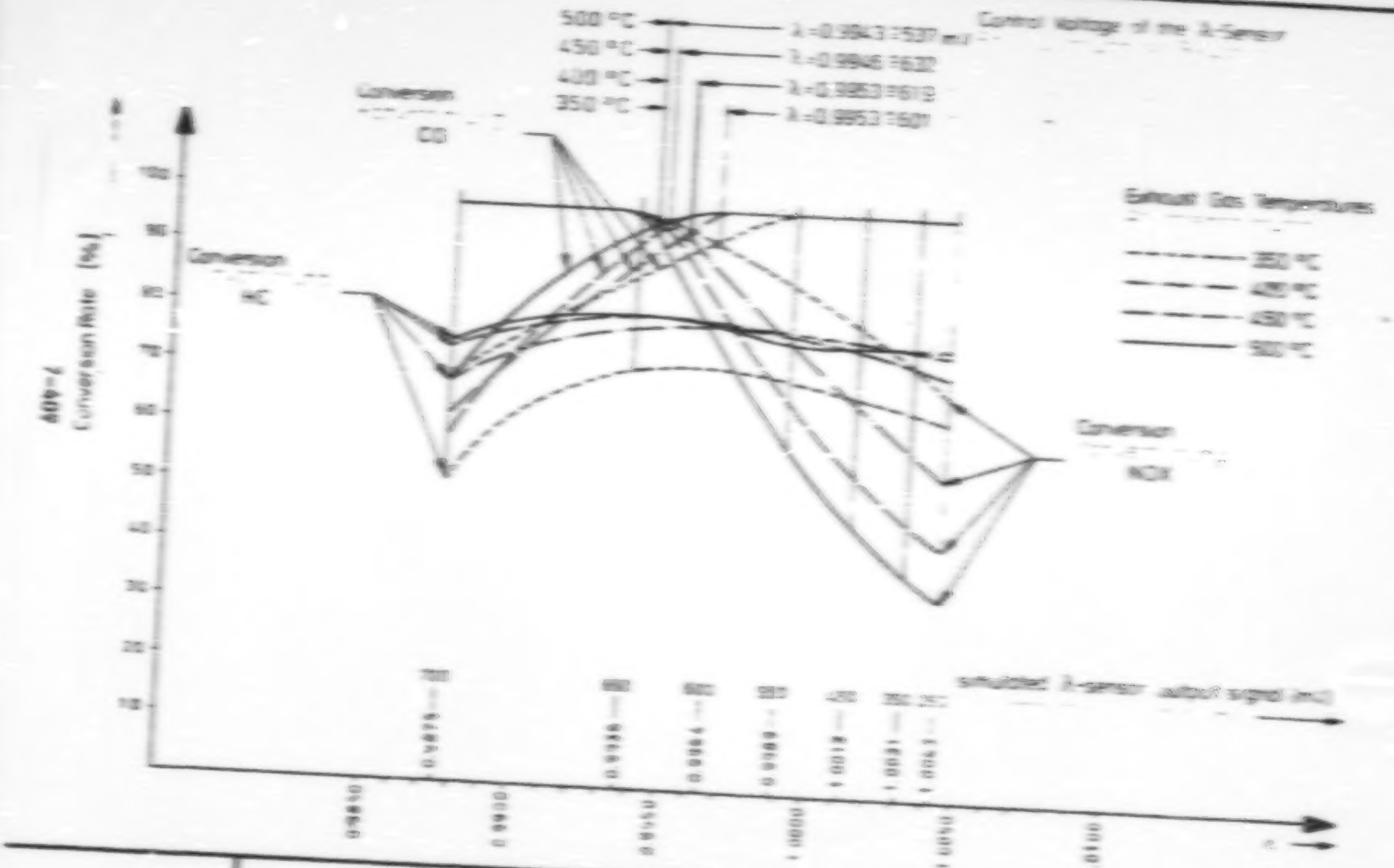


Figure VW-3

Exhaust emission chromatogram at the outlet of the catalyst (column II)



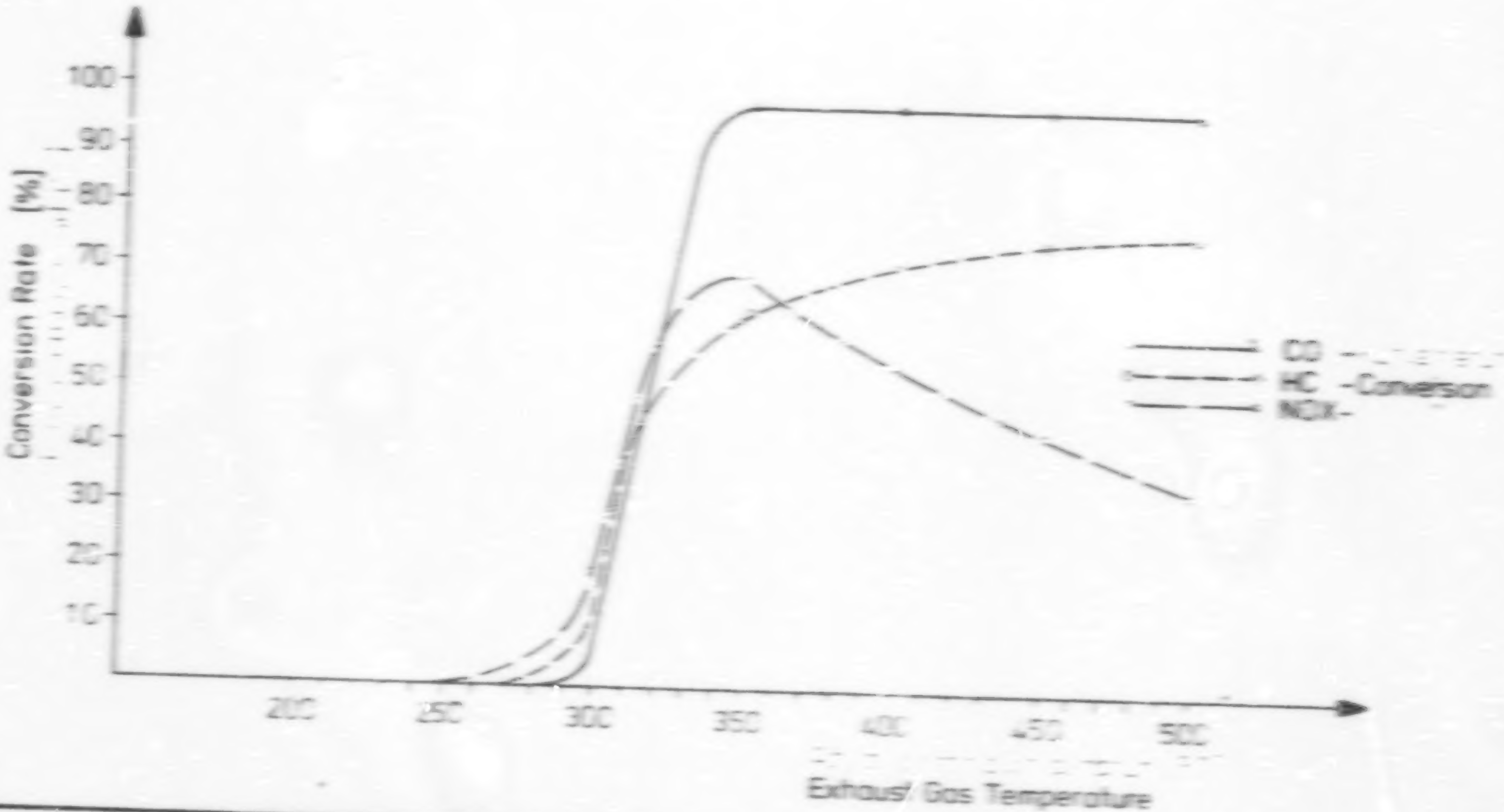
Optimal CO-NOX - Conversion = f
(Exhaust Gas Temperature)

Figure [illegible]

lean side of stoichiometry at λ^* = 1.0043 (Figure VW-5) NOx conversion efficiency reaches 70% at 350°C and decreases with increasing inlet temperature while the CO and HC conversion rates continue to increase. At a rich air fuel ratio of λ = 0.9875 (Figure VW-6), the CO conversion reaches its maximum at 350°C and decreases at higher temperature. The NOx and HC conversion rates increase at higher temperatures. These above results were obtained with the sensor control voltage held constant for each air-fuel ratio: 350 mV for for lean ratio and 700 mV for the rich ratio. When the voltage was varied with temperature, the optimal conversion rates for all three pollutants were obtained. The optimal control voltage varied from 580 mV for 350°C to 637 mV for 500°C. VW indicated that the optimal conversion profile as indicated in Figure VW-7. This has important implications for optimizing 3-way catalyst performance.

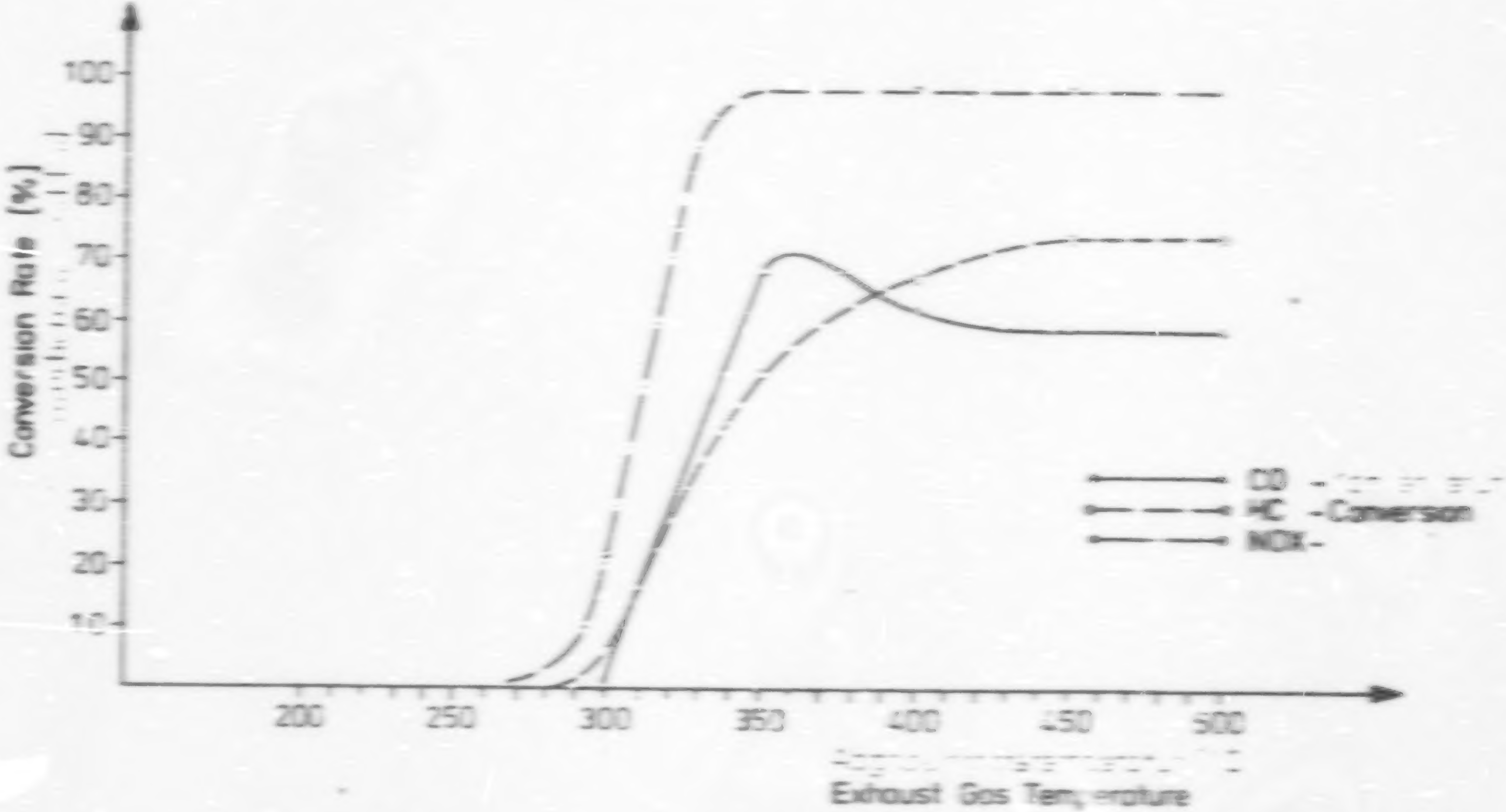
VW also reported the results of their investigation of using different O_2 sensor materials. VW concluded the most common type of platenum sensor was the more suitable sensor for use when calibrating the 3-way system to maintain a stoichiometric air-fuel ratio. However, as Table VW-1 indicates, other sensor materials cannot only widen the control range but also bias the sensor signal either richer or leaner than stoichiometric. This indicates that depending on the manufacturers calibration philosophy, there are other sensor materials available which could allow air-fuel ratio control other than at stoichiometric.

$$* \lambda = \frac{\text{air-fuel ratio (actual)}}{\text{air-fuel ratio (stoichiometric}}$$



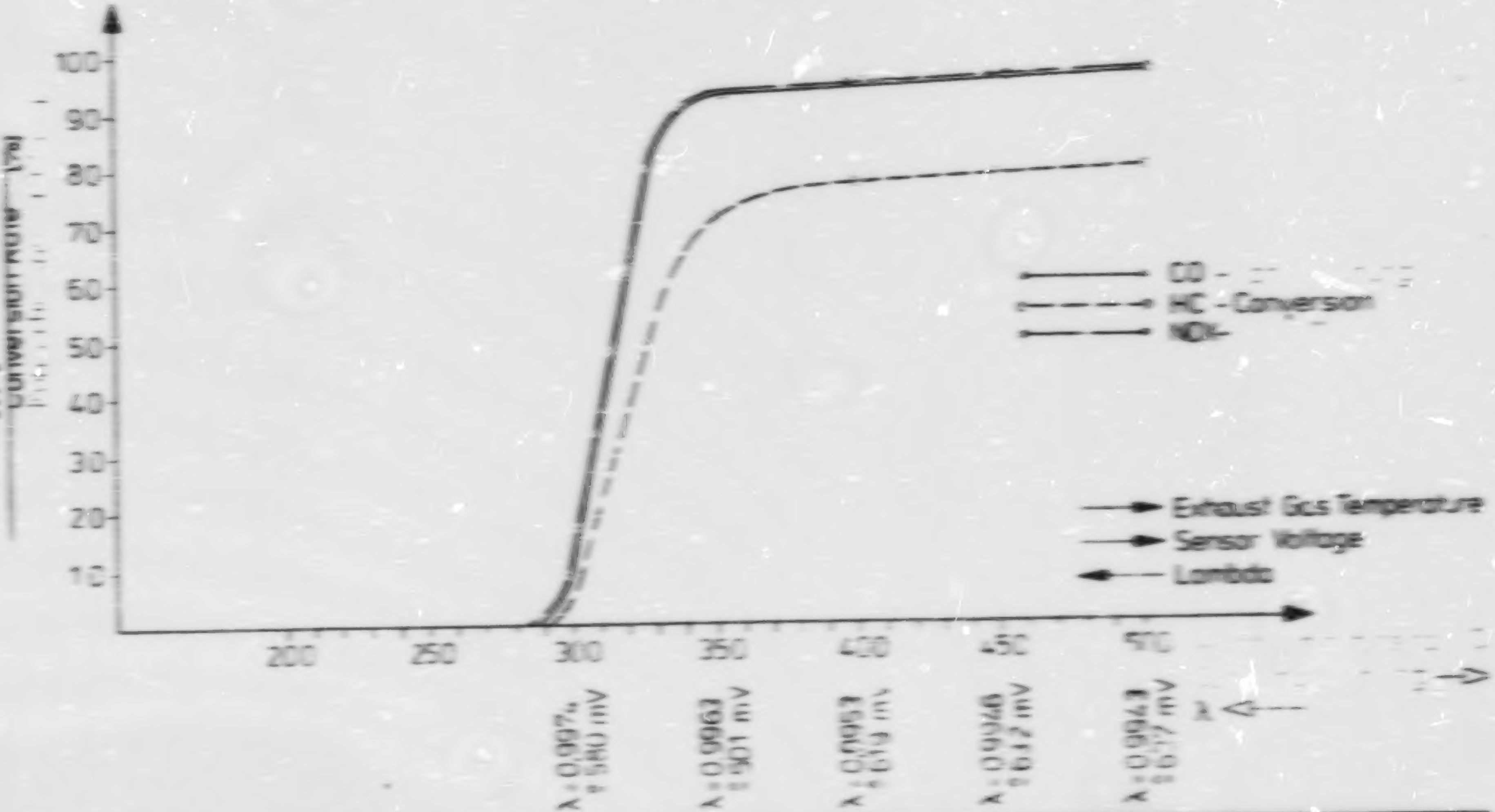
Conversion CO, HC, NOX = f (Exhaust Gas Temperature) at λ = 1,0043 ≙ 250 mV

Figure 16-5



Conversion CO,HC,NOX = f (Exhaust Gas Temperature) at λ =0,9875 ≙ 700 mV

Figure 19-6



Optimal Conversion = f (λ and
Exhaust Gas Temperature)

Figure 18-7

Table VW-1

Response Width and Maximum Response of Different O_2 Sensor Materials

Sensor	Response width (mV)	Maximal Rise Occurs Between
Pt-activated "spinell"	From 40-90 mV at λ = 1.16 up to 880 mV at λ = 0.84	λ = 1.03 and λ = 0.99
Common type with Pt-Filter	From 60-90 Mv at λ = 1.16 up to 840 mV at λ = 0.84	λ = 1.01 and λ = 0.99
Yttrium	From 35-70 mV at λ = 1.16 up to 920 mV at λ = 0.84	λ = 1.04 and λ = 1.0

VW reported a limited amount of low mileage emission test data for developmental 3-way catalyst systems. Table VW-2 shows the latest reported emission results from systems targeted at the 0.41 HC, 3.4 CO, 1.0 NOx level.

Table VW-2

System	HC	CO	NOx	MPG_U
air cooled engine, L-Jetronic EFI, O_2 sensor, 3-way catalyst	0.23	2.83	0.46	-
water cooled engine, K-Jetronic CFI, O_2 sensor, 3-way catalyst	0.35	2.20	0.40	-
water cooled engine, feedback carburetor, O_2 sensor, 3-way catalyst	0.27	2.80	0.87	22.8

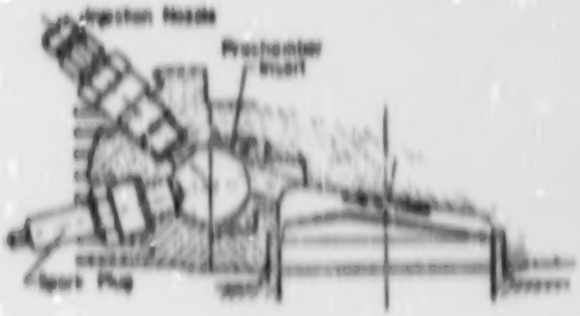
VW reported that the 3-way catalyst was developed in the same way as the oxidation catalyst for MY 77 in that the substrate was increased from 200 cells per square inch to 300 cells per square inch. VW did not report work on any 3-way plus oxidation catalyst or dual catalyst systems.

Other Development Efforts

PCI

VW has been working on two divided chamber, stratified charge engines. One of these is a three valve engine with a scavenged prechamber which resembles in principle the Honda CVCC. The second engine of this type uses an unscavenged prechamber and is call the Pre-Chamber-Injection (PCI). The PCI is shown in Figure VW-8.

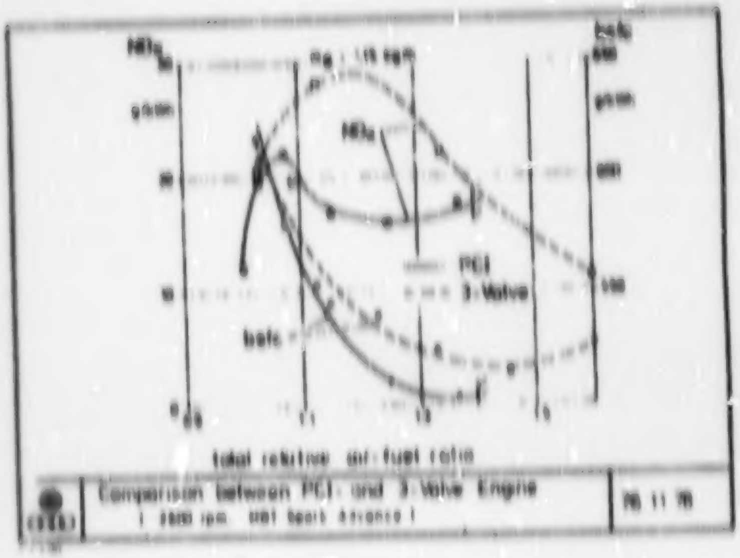
Figure VW-8
PCI Combustion Chamber



These concepts were originally tailored to their air cooled engines but have, more recently, been adapted to their water cooled engines. VW's current status report indicated that their interests and efforts have shifted to the PCI concept because it has demonstrated significantly better NOx control and lower fuel consumption than the three valve concept. Figure VW-9 shows these relationships.

Figure VW-9

Comparison of PCI and 3-Valve Engine

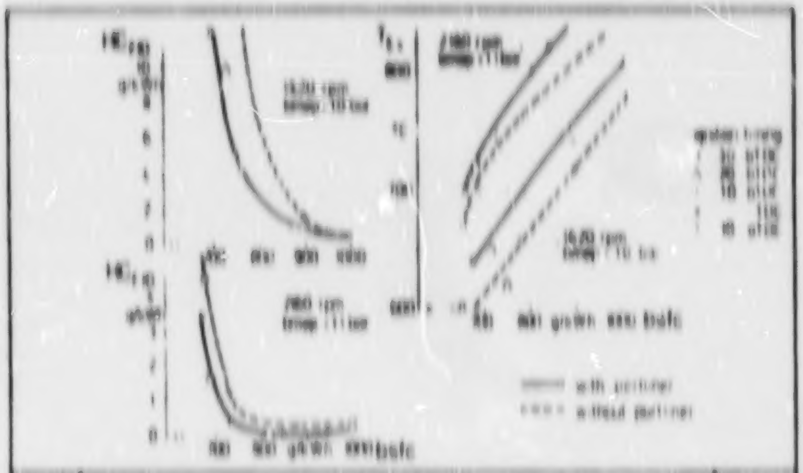


Comparison between PCI- and 3-Valve Engine
(2000 rpm, MBT Spark Advance)

Data taken at the same operating conditions reveal the NOx advantage of the PCI system, even at a lower brake specific fuel consumption according to VW. This difference is most pronounced at a total relative air-fuel ratio that is optimal for HC and CO oxidation in the exhaust system. The indicated misfire limit for the PCI system is typical only for a very late injection timing, according to VW.

VW has added port liners to the PCI system to increase inlet temperatures to the lean thermal reactor incorporated in the system. The exhaust ports of the cylinder head were enlarged and modified so that long port liners could be inserted without causing a significant flow restriction. Because of the higher reactor inlet temperature, reactor conversion, particularly at light engine load, can be significantly increased or ignition timing can be chosen for less fuel economy loss. Figure VW-9 shows that a temperature increase of 30° to 40° C resulted in lower HC emissions of up to 50% at the same spark timing or in a reduction in fuel consumption of 5 to 10% if the HC level was maintained.

Figure VW-9



Effect of Portliners on Exhaust Gas Temperature and HC Emissions 76 11 81

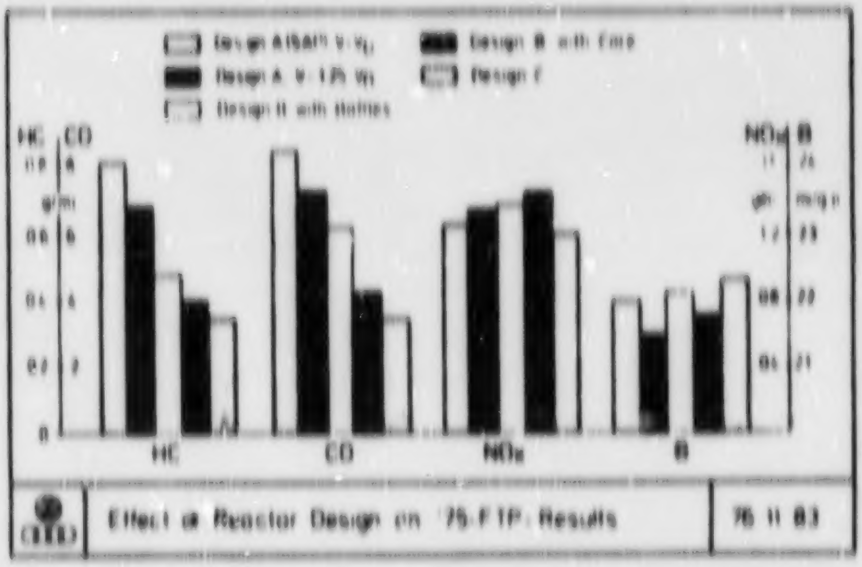
Maximum engine power output is reduced by approximately 5-8%. This stems primarily from modifications of the exhaust system, not as is often assumed from a slower burn rate. The higher back pressure at the exhaust ports caused by the reactor results in a noticeable reduction of volumetric efficiency at high engine speeds.

VW claims that if regular fuel is used, the compression ratio should be less than 9:1 to have a sufficient margin from the knock limit. This will also keep combustion noise down to levels that are typical of Otto engines. An analysis of cylinder pressure diagrams showed values for the pressure gradient of 1 to 2.5 bar/degree crankangle under typical operating conditions. Under extreme conditions, a value of approximately 3 bar/degree crankangle was measured, still far below the values of prechamber diesel engines.

Exhaust analysis for soot with the Bosch tester gave only than a few tenths on the BOSCH-scale.

Various types of lean thermal reactors were built and tested. For example, a design with a design with a cast iron casing, air insulation for the inner core (Design A) with the provision to preheat the air-fuel mixture by exhaust heat or, in the more conventional manner by the engine coolant. In another effort, an all sheet metal design with fiberfrax insulation (Design B and C) was chosen. A summary of emission results obtained, and the fuel economy measured, is given in Figure VW-

Figure VW-10



10. It shows the progress made in HC and CO emission by first increasing the core volume of design A by approximately 25% and during the second series of steps with the design B. In design C, heat losses of the gases, when passing from the exhaust port into the reactor core, were reduced by appropriate shields. It should be noted that the system with the lowest emissions in Figure VW-10 had the best fuel economy.

The significance of the warm-up behaviour following a cold start during the FTP is convincingly expressed in Figure VW-11. Results were obtained with the PCI-concept and without employing exhaust heat for mixture preparation. The first and last 505 s are already weighted 43 to 57. Particular attention is to be paid to HC and CO emissions from Bag 1, which are 3 to 4 times greater than those in Bag 2. Here again, as in practically all other cases shown, the major portion is caused during the acceleration and cruise mode. Improvements through careful optimisation of the cold start phase will have a significant effect on the FTP results. Only a very intensive application of exhaust heat to the intake manifold will result in a quicker increase in mixture temperature when compared with a water-heated intake manifold. This would, on the other hand, require a control to limit the heat exchange at high engine load.

At the emission levels reported here, an evaluation of the driveability gave good to very good ratings. No particular problems with vehicles that are being tested under daily traffic conditions have appeared thus far. However, no vehicle durability run has yet been made to determine emission deterioration factors and cold start problems were encountered.

"May-Fireball" Combustion Process

VW reported on their ongoing evaluation of the "May-Fireball" combination process. This process was developed by a research laboratory entitled: "Antipollution Industrial Research S.A.". This engine reportedly produces a high swirl rate and has a novel combustion chamber design. The combustion chamber is positioned around the exhaust valve as shown in Figure VW-12.

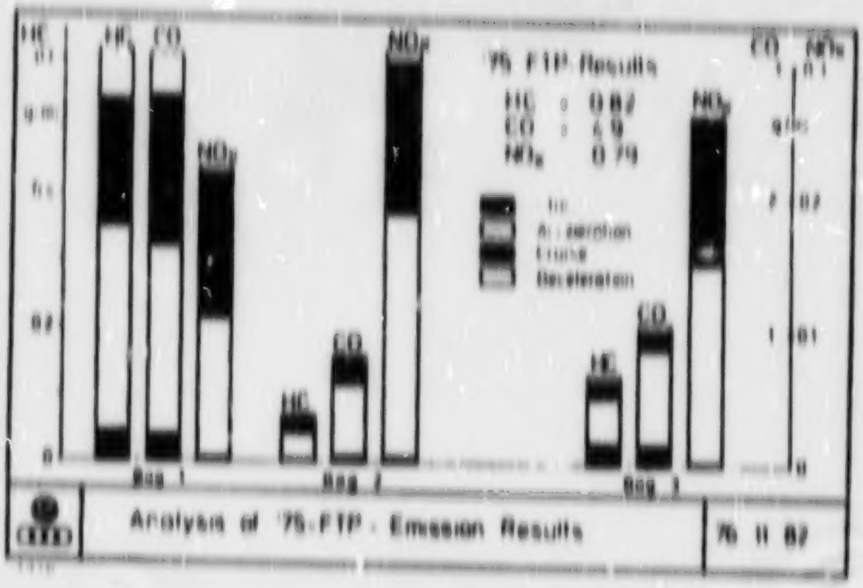
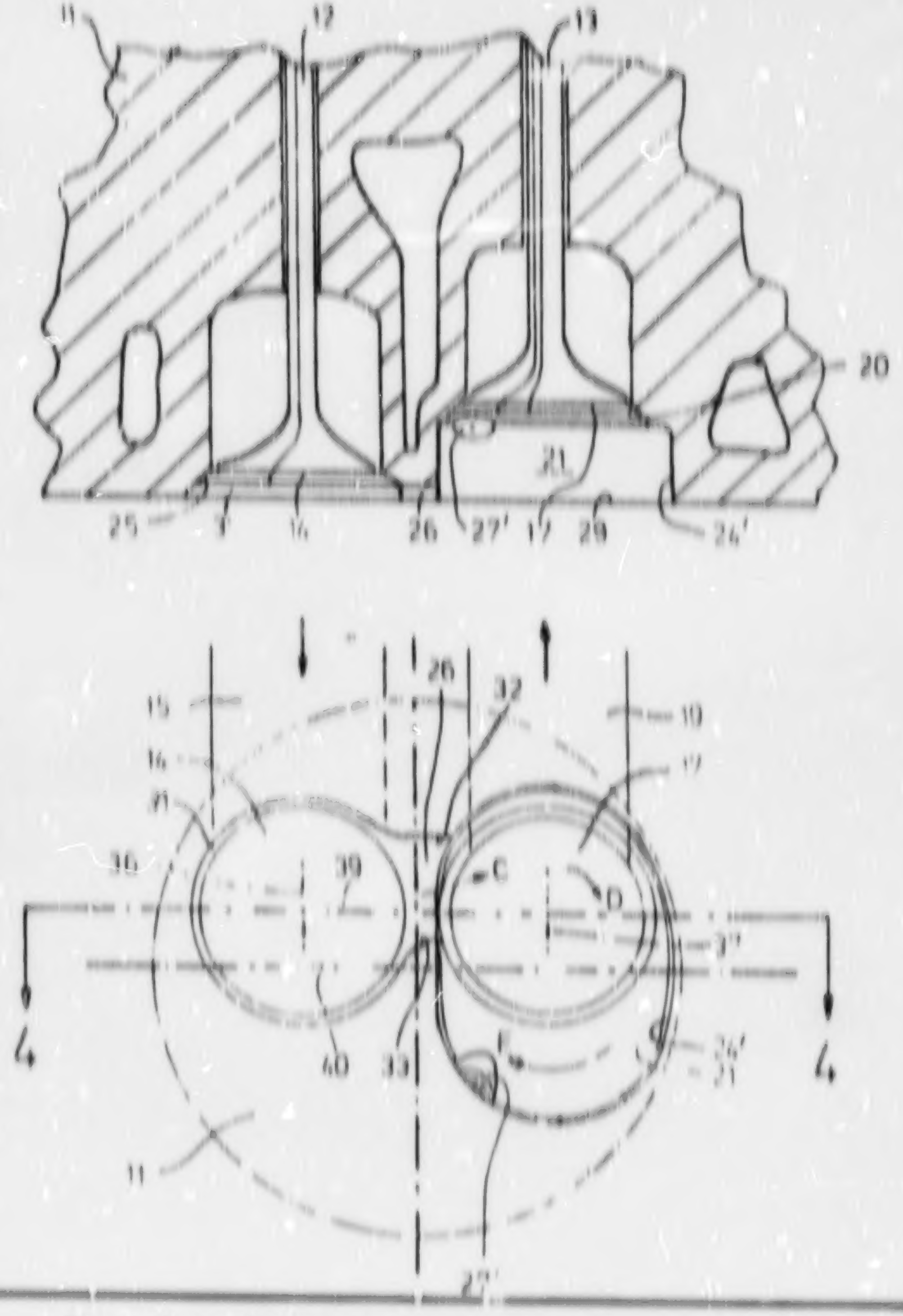

HC
HC
CO
NOx
NOx
'75 FTP Results
HC : 0.82
CO : 4.9
NOx 0.79
Idle
Acceleration
Cruise
Deceleration
g/mi
0.2
0
HC
CO
HC
CO
NOx
CO
NOx
g/mi
2
1
0.01
0
Bag 1
Bag 2
Bag 3
Analysis of '75-FTP - Emission Results
76 11 82

Figure VW-11


11
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34'
4
4
11
27'

Figure VW-12 "May-Fireball" Combustion Chamber

It has been claimed that this process allows the compression ratio to be increased to as high as 15.8 to 1.

VW has evaluated one engine of this type. This was a 90 CID Dasher engine adapted to the May-Fireball process. It was equipped with K-Jetronic fuel injection and installed in a Dasher. In a fuel economy comparison between a carbureted version of the Dasher engine and a Diesel version of this engine the May-Fireball was equivalent to the Diesel and substantially better than the standard Dasher engine. See Figure VW-13.

In emission testing the May-Fireball equipped Dasher measured 2.1 HC, 3.7 CO, 1.9 NOx. It is presumed that this was without the benefit of any emission control components. It appears that the major emission problem is HC. VW did not indicate whether or not this engine required high octane fuel but with a compression ratio of 15.8 to 1, it is likely that it did. The octane level requirements of 97-98 octane was confirmed by the inventor, M. G. May, at the Champion Ignition and Engine Performance Conference in Vienna, Austria. High octane requirements will complicate emission control of this engine since for example they may necessitate leaded fuel which is not compatible with current catalysts.

Diesel Engines

The following results are representative of results achieved by the VW Diesels during MY 1977 Certification testing. The emission results include DF of 1.0 for HC and CO and 1.308 for NOx.

Table VW-3

VW Diesel Results

Model	HC	CO	NOx	MPG_u	MPG_h	MPG_c
Dasher	0.46	1.00	1.50	35	47	40
Rabbit	0.30	1.00	1.37	39	51	44
Rabbit*	0.78	1.00	0.80	50	65	56

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* Fuel economy improvement package, including different axle ratio.

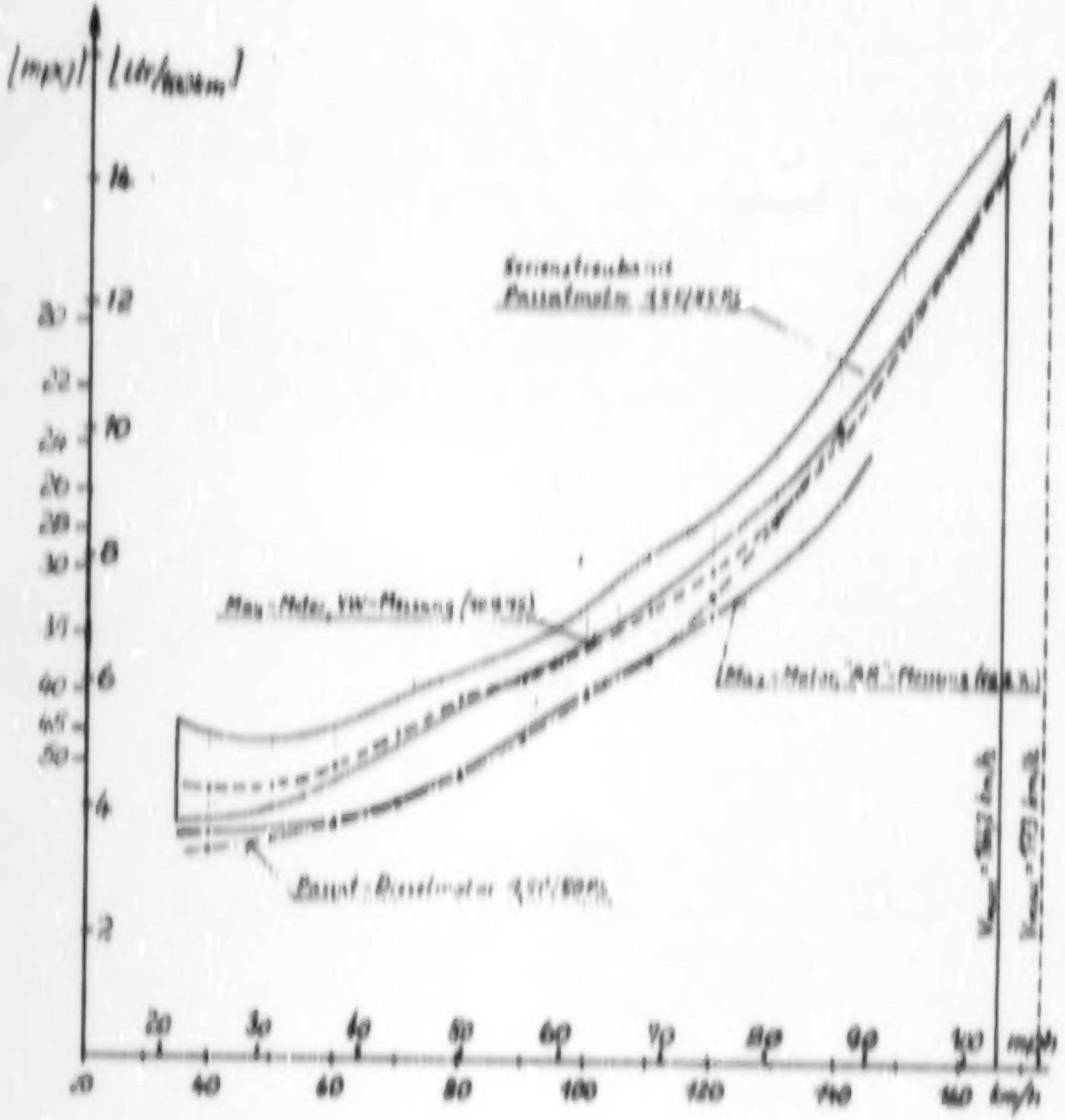


Figure VW-13 "Hay-Fireball" Fuel Combustion Results

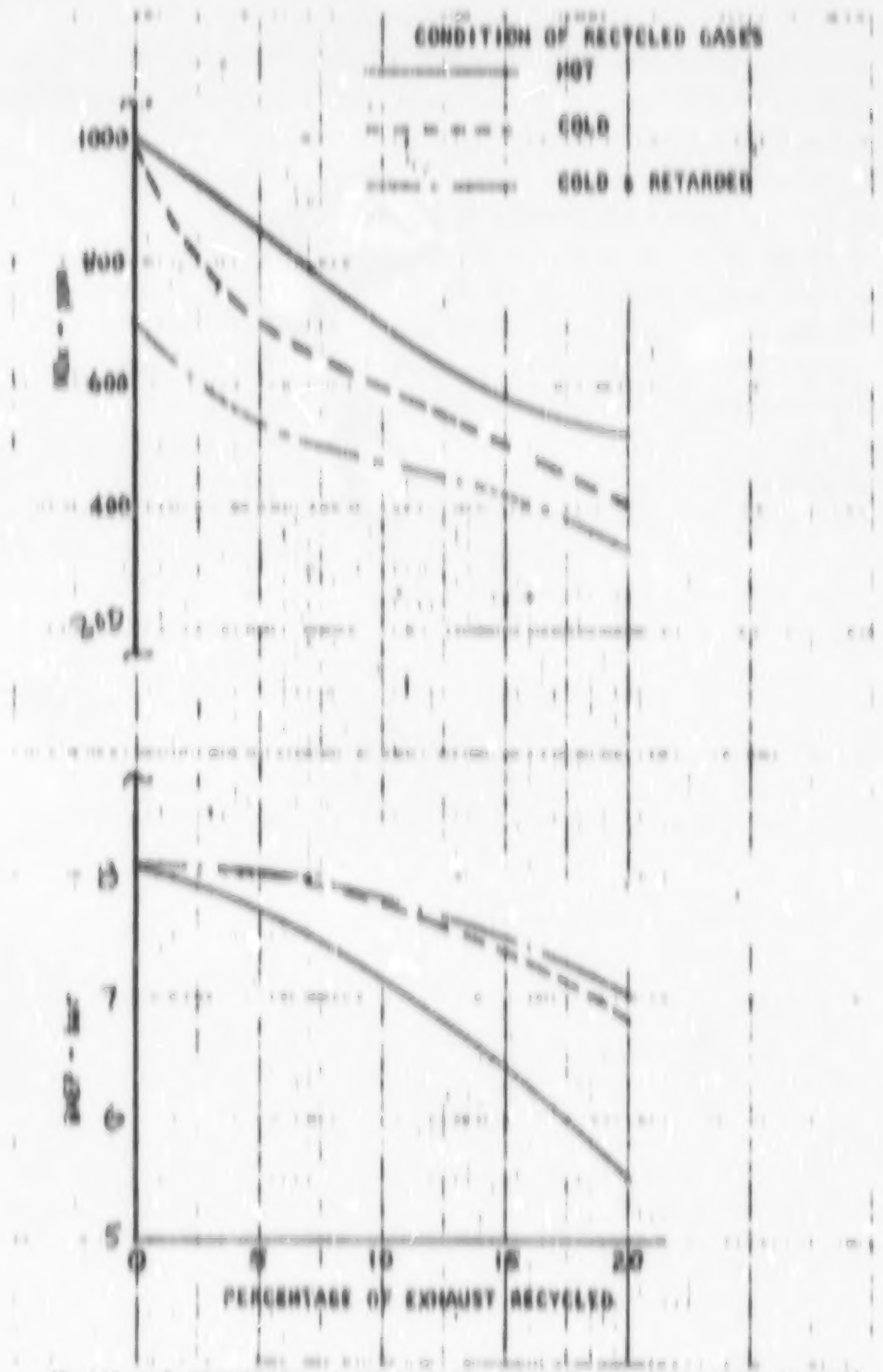
VW has been investigating the effect of injection retard and EGR, both with and without cooling, on the Diesel engine emissions. Figure VW-14 presents data taken from their report.

VW did not report fuel economy or HC and CO data for the testing shown in Figure VW-14. They did, however, present more complete emission data for a series of CVS tests. Figure VW-15 portrays the results of this testing which evaluated the effect of injection timing. VW did not specify what engine or vehicle was involved in this testing, nor did they indicate what type of CVS testing was conducted.

As can be seen from the above two figures, EGR and injection retard can have potent effects upon NOx without seriously degrading HC, CO, or fuel economy. VW indicated that cooled EGR was more promising than injection retardation, but they were equally concerned about condensation and deposit problems as well as the size and weight requirements of the EGR intercooler used.

7.3.16.2. Systems to Meet Various Emission Levels

Table VW-4 shows VW's first choice systems to meet future emission levels.



(% EGR = % REDUCTION IN VOLUME OF AMBIENT AIR FLOW INTO ENGINE)

Figure VW-14

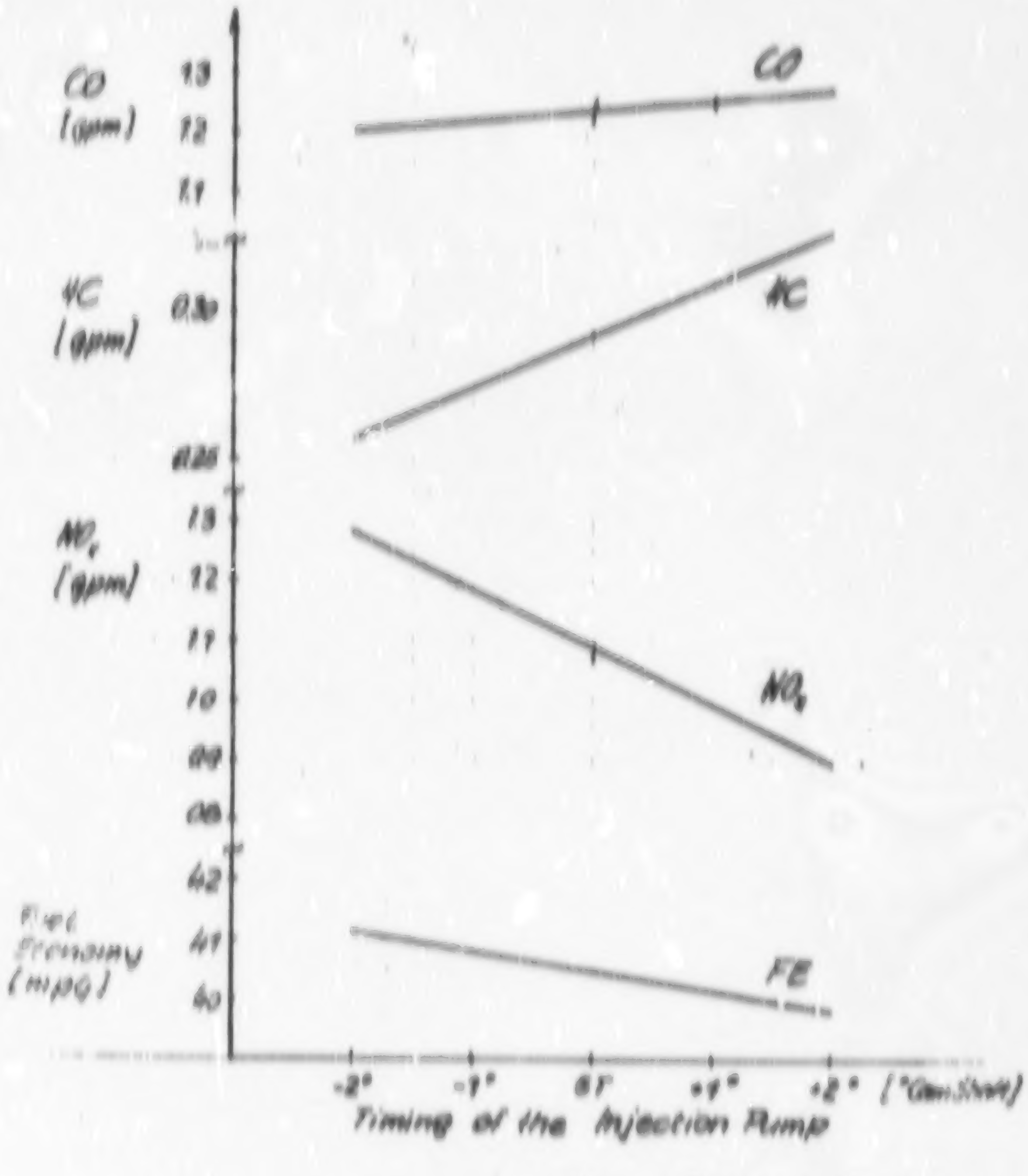


Figure VW-15

Emissions, Fuel Economy, and Injection timing during CVS-Test

Table VII-4

Future Emission Control Systems

Engine	1.5 HC 15 CO 2.0 NOx	0.41 HC 9 CO 1.5 NOx	0.41 HC 3.4 CO 2.0 NOx	0.41 HC 3.4 CO 1.0 NOx	0.41 HC 3.4 CO 0.4 NOx
Air Cooled L-Jetronic (EFI)	Engine Mods EGR	Engine Mods EGR Ox. Cat.	Engine Mods EGR Close coupled Ox. Cat.	Engine Mods Oxygen Sensor & Feedback 3-way catalyst	Engine Mods Oxygen Sensor & Feedback 3-way catalyst
Water Cooled Carburetor	AIR Ox. Cat. EGR	-	AIR Ox. Cat. EGR	Engine Mods Oxygen Sensor & Feedback 3-way catalyst	Engine Mods Oxygen Sensor & Feedback 3-way catalyst
Water Cooled K-Jetronic (CIS)*	Engine Mods EGR	Engine Mods EGR Ox. Cat.	Engine Mods EGR Ox. Cat.	Engine Mods Oxygen Sensor & Feedback 3-way catalyst	Engine Mods Oxygen Sensor & Feedback 3-way catalyst

* Continuous Injection System

7.3.16.2. Durability Testing

VW reported the data in Table VW-5 which is assumed to indicate VW's predurability calibrations on a system of K-Jetronic and improved oxidation catalyst applied to their water-cooled engines from 1978 California vehicles. What is significant about these data are the results indicate that NOx levels approaching 1.0 gm/mi or below could be achieved on smaller vehicles with fuel injection and an oxidation catalyst. It should also be noted that as NOx is reduced HC and CO levels approach the statutory levels of 0.41 and 3.4 and may not be sufficiently low enough to assure certification at 0.41 HC, 3.4 CO, and 1.0 NOx.

Table VW-5

VW Durability Test Data at Low Mileage

Audi Fox, K-Jetronic + OC, M4

FTP - Results (gm/mi)

HC	CO	NOx
0.30	1.42	1.29
0.24	2.02	1.15
0.29	2.64	1.06
0.29	3.20	1.06
0.37	4.86	0.62

VW also reported two vehicle durability tests of systems targeted at the 0.41 HC, 3.4 CO, 1.0 NOx level. Table VW-6 shows the results of this testing. No catalyst descriptions were provided.

Table VW-6

Durability Testing

System	Mileage	HC	CO	NOx
Air cooled eng., L-Jetronic, O_2 sensor, 3-way cat., No EGR	0	-	-	-
	18,600	0.45	4.70	1.16
	20,500	0.30	4.00	0.48
	21,300	0.43	1.56	2.27
	25,113	0.41	3.22	1.00
	25,135	0.53	5.67	1.03
	30,845	0.95	7.65	1.06
	30,845	0.20	3.26	0.47
	38,400	0.33	3.60	1.30
	46,700	0.40	4.60	0.90
	50,000	0.29	3.56	0.89

While the above data is not that impressive, it was unclear why the various tests reported varied so dramatically. A second vehicle assumed to be equipped identically to the one above showed the following results at low mileage:

	HC	CO	NOx
Test 1	0.21	1.98	0.50
2	0.17	2.22	0.46
3	0.15	1.78	0.65
4	0.15	1.78	0.83
5	0.16	1.54	0.92
6	0.13	2.08	0.88

Test six may be a better indication of this system's potential.

Table VW-6 (con't)

Water cooled eng., K-Jetronic, O_2 sensor, 3-way cat., NO EGR	0	0.18	0.96	0.72	
	5,000	0.25	1.83	0.55	
	10,000	0.23	1.26	1.12	
	15,000	0.78	8.77	0.66	
	20,000	0.87	13.42	0.92	Change λ - sensor
		0.39	2.20	1.46	
		0.13	1.24	1.22	
	25,000	0.16	1.17	1.13	
	30,000	0.14	1.59	0.63	
	35,000	0.30	3.10	0.33	
	40,000	0.97	13.81	0.27	Change λ - sensor
		1.03	14.46	0.40	

VW also reported other 3-way data as shown in Table VW-7.

Table VW-7

3-Way Catalysts Zero Mile Test Results

Tests Performed At	FTP Results (gm/mi) HC	CO	NOx
Ingolstadt	0.18	1.15	0.71
	0.23	1.79	0.74
	0.26	1.26	0.65
EPA Ann Arbor	0.15	1.47	0.83
	0.14	0.94	0.94
	0.15	0.93	0.82
Ingolstadt	0.30	2.25	0.73
	0.32	1.64	0.76
	0.18	1.45	1.05
	0.21	1.67	0.57

7.3.16.4. Progress and Problems

VW has not shown much progress in the development and testing of 3-way catalyst systems to meet lower NOx standards. However, the data presented indicates that the potential for achieving 10.41 HC, 3.4 CO, 1.0 NOx with 3-way catalyst system exists for low inertia weight vehicles. Some progress has been made on their PCI concept but this engine seems to be a long way from production.

VW's progress in reporting and/or adapting EGR and other NOx control measures to their Diesel engine has also been slow. Only a limited amount of exploratory investigation and testing were reported in this important area.

7.3.17. Volvo

7.3.17.1. Systems Under Development

Oxidation Catalyst Systems

Volvo continues to work on oxidation catalyst systems. There are three basic systems all employing oxidation catalysts and EGR. The systems differ in the type of secondary air used. One system uses no additional air injection, another uses a Saginaw (GM) air pump driven at 85% of engine speed, and the third system uses a pulsair air introduction system.

The no-air system is the current system used by Volvo for the Federal standards. Apparently, only the air pump and the pulsair systems are being developed for emission standards more stringent that the 1977 Federal standards.

Of the two systems (pulsair and air pump) Volvo prefers the pulsair system, because Volvo sees fuel economy, cost, power, and possibly sulfuric acid benefits with the pulsair system over the air pump system.

The pulsair system has been applied to both of Volvo's current engines, the B21 (4 cylinder in-line configuration) and the B27 (6 cylinder "V" configuration). Results on the B21 have shown promise, but there have been backflow and noise problems with the B27.

The Volvo pulsair system introduces about 20% air injection from idle to 1500 RPM, reduces this to 3% between 1500 and 2500 RPM, and remains 3% from 2500 to 3500 RPM. Volvo did not indicate the basis for the determination of the percent air injection values. The system also contains what Volvo calls an "NRV" (non-return valve) which is assumed to be a check valve typical of pulsair systems.

Volvo has experimented with different MRV configurations. Apparently, the most effective one was with one MRV for cylinders 1 and 4 and one MRV for cylinders 2 and 3.

The pulsair system was tested on a vehicle with a B21F engine, automatic transmission, oxidation catalyst, and EGR.

The results of the testing, baseline compared to the most effective pulsair system, are shown in Table Volvo-1.

Table Volvo-1

Effects of Pulsair*

HC	CO	NOx	MPG_U	Comments
0.643	13.0	1.43	17.2	2% idle CO, no air
0.250	3.94	1.89	16.3	2% idle CO, pulsair
0.662	16.0	1.53	17.1	3% idle CO, no air
0.265	4.27	1.53	17.5	3% idle CO, pulsair

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* Volvo Status Report, page 59.

Testing has also been done with the B27 engine, apparently investigating different MRVs. The results are shown in Table Volvo-2. The testing was conducted on an unspecified vehicle equipped with a catalyst.

Table Volvo-2

Effects of Pulsair*

HC	CO	NOx	Comments
0.23	2.02	1.99	3 valve sytem, 2 APG, 1AC
0.18	1.60	1.78	3 valve system, AC valves

---

* Volvo Status Report, page 69, page 71.

Tests were also run on vehicles equipped with B27 engines, apparently testing different air injection systems. The different configurations were labeled "standard air manifold" and "8mm air manifold". The results are shown on Table Volvo-3.

Table Volvo-3

Effect of Different Air Manifolds*

Configuration	HC	CO	NOx	Comments
Standard	0.35	1.64	1.37	6 test ave, 1.8% CO
8mm	0.34	1.41	1.50	5 test ave, 1.8% CO
Standard	0.26	1.31	1.74	5 test ave, 1.7% CO
8mm	0.21	1.21	1.71	5 test ave, 1.7% CO

---

* Volvo Status Report, page 70.

Currently, Volvo uses an oxidation catalyst produced by Engelhard, called by Volvo the PTX 514.5. For more stringent standards Volvo may use the PTX 516. The catalysts are described in the following table.

Table Volvo-4

Volvo Oxidation Catalysts*

Type	Volume	Active Materials, (Ratio)	Total Active Loading Troy oz.	Dia/ Length	Loading, gm/cu ft.
PTX 514.5	77 cu ft.	Pt/Pd (2:1)	0.036	4.66/4.5 in	approx. 25
PTX 516	102 cu ft.	Pt/Pd (2:1)	0.095	4.66/6 in	approx. 50

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* Volvo part I, page VI 117, 118.

As can be seen from Table Volvo-4, the two catalysts differ in both length and specific loading (gm/cu ft.).

Volvo reported work on choke optimization with a 3500 IW vehicle equipped with the 76 B27 engine, an air pump, EGR, and a PTX 516 oxidation catalyst. Tests were run with choke times of 45, 62, 75, and 90 seconds. It appears that the choke time of 75 seconds yielded the best results for HC and CO. There was some scatter in the data, especially for HC. The results are shown in Table Volvo-5. No data were provided to compare the vehicle driveability at the various choke time settings.

Table Volvo-5

Effect of Choke Time*

Choke Time Seconds	HC	CO	NOx	MPG_u	MPG_h	MPG_c	Comments
45	0.09	1.21	1.26	14.3	-	-	
45	0.25	1.63	1.38	14.1	19.1	16.0	
ave	0.17	1.42	1.32	14.2	19.1	16.1	
62	0.24	1.39	1.66	14.0	22.8	16.9	1 Restart
62	0.15	1.33	1.35	13.5	-	-	
ave	0.20	1.36	1.51	13.8	22.8	16.8	
75	0.04	1.13	1.64	13.3	-	-	
75	0.06	1.12	1.49	13.7	21.8	16.5	
ave	0.05	1.12	1.57	13.5	21.8	16.3	
90	0.29	1.70	1.55	13.6	-	-	1 Restart
90	0.18	1.49	1.55	13.2	23.6	16.5	
ave	0.24	1.60	1.55	13.4	23.6	16.6	

* Volvo Status Report, page 67.

Volvo reported little development or durability testing with other oxidation catalyst types.

3-Way Catalyst Systems

Volvo has an extensive development program underway on 3-way catalysts. Volvo's efforts in this area are so extensive, compared to other potential systems, that it is concluded that Volvo is concentrating almost all of their efforts for future emission control systems on the 3-way catalyst system.

Volvo's emphasis on the 3-way catalyst system has resulted in the commercial introduction by Volvo of a 3-way catalyst system. This system is the one on the 1977 California vehicles equipped with a B21-engine. This makes Volvo the world's first manufacturer to introduce a 3-way catalyst emission control system on production vehicles.

The basic Volvo system consists of the 3-way catalyst, an oxygen sensor, and a feedback controlled fuel injection system. Volvo uses a 3-way catalyst manufactured by Engelhard. Volvo and Engelhard have worked together closely in the development of the 3-way catalyst system. The catalyst is the PTX 516, which apparently is also called the TWC-16. It is generally like the PTX 516 oxidation catalyst described in Table Volvo-4, except that its active materials are Pt/Rh in a 5 to 1 ratio. Volvo states that because they are such a small consumer of precious metals, the supply of Rhodium should be no problem for them, even though the Pt/Rh ratio in their 3-way catalyst is higher than the naturally-occurring or "mine-mix" ratio of approximately 19/1.

Volvo has completed much of the necessary development work for the 3-way catalyst system for the B21 engine applications. When tested at EPA, the emission data vehicles with the 3-way catalyst system produced the results shown on Table Volvo-6.

Table Volvo-6

Range of Low-Mileage (4000 mile)
Emission Data for Volvo 3-Way Catalyst Vehicles

HC	CO	NOx	MPG_u	MPG_h	MPG_c
0.17-0.22	2.4-3.3	0.07-0.18	16.0-18.7	25.4-31.4	21.1-22.4

These low mileage values, coupled with the DFs for this family of 0.824, 0.896, and 1.141 for HC, CO, and NOx respectively (1, 1, and 1.141 for official purposes) might lead one to infer that the Volvo 3-way catalyst car met the statutory emission levels of 0.41 HC, 3.4 CO, 0.4 NOx. This is not exactly the case, because, in addition to the 4000 mile times DF results being below the standards, the durability car cannot "line cross". The line crossing prohibition means that the least squares line through the durability car data points cannot exceed the standards at 4000 miles or at 50,000 miles. The Volvo 4000 and 50,000 (4K and 50K) mile results are shown on Table Volvo-7.

Table Volvo-7

4K and 50K Results
For Volvo 3-Way Catalyst Durability Car

Mileage	HC	CO	NOx
4K	0.27	3.83	0.37
50K	0.22	3.43	0.42

As can be seen from the above table, the Volvo durability car line crossed at 4K for CO. There were no problems with HC. The NOx value was very close to the standard of 0.4 grams per mile at the 50K point. In fact, were the statutory NOx standard expressed as 0.40 grams per mile instead of the official value of 0.4, the Volvo vehicle would have line crossed at 50K for NOx.

The important point about these results is that they show for the first time, a vehicle run on official EPA certification durability that came close to meeting the statutory standards of 0.41 HC, 3.4 CO, 0.4 NOx. If the standards were 0.41 HC, 4.0 CO, 0.4 NOx instead, the Volvo vehicle would have met them.

With much of the development work done for the B21, Volvo is now apparently concentrating on the development of the 3-way catalyst system for the B27 application.

Volvo will try to certify the B27/3-way catalyst system for California for model year 1978. The catalyst to be tried will be identical to the 1977 catalyst for the B21. Volvo states that the reason for this is that the B27 application can probably meet the assumed 1978 California requirements of 0.41 HC, 9.0 CO, 1.5 NOx with the TWC-16, and having only one 3-way catalyst simplifies certification and catalyst supply problems. It should be noted that Volvo indicated that the B27 was basically a higher emitting engine than the B21, and thus needed the TWC-16 to reach the California-required levels. Since the B27 engine is larger in displacement than the B21 (163 vs. 130 CID), in order to get to lower standards than the California standards, it may be necessary for Volvo to increase the loading and/or the volume of the 3-way catalyst on the B27 in order to approach the performance already demonstrated with the B21 applications.

An area of concern to Volvo in the B27 program is related to the "V" configuration of the B27 engine. With two exhaust manifolds the crossover pipe design, sensor and catalyst positioning, and light-off have been important design/development areas.

The exhaust system has been modified on the 1978 California vehicle to provide a shorter crossover so that the single oxygen sensor can be placed closer to the engine for rapid light-off. The catalyst location is apparently not changed, from the oxidation catalyst system, being approximately 38 inches from the exhaust manifold.

Volvo feels that this sensor/catalyst configuration will be sufficient to give them enough control for the 0.41 HC, 9 CO, 1.5 NOx California target values.

For future applications two approaches are being explored. The first is the insulation of the current production exhaust system, and the second is the so-called "super-short" exhaust system in which the left hand exhaust pipe goes over the transmission. This configuration makes the union between the two exhaust pipes even closer to the exhaust ports and may allow for even faster sensor light-off. In addition, the super-short system may allow for catalyst repositioning closer to the engine next to the transmission.

The two approaches (insulation and the super-short exhaust system) show "considerable potential" according to Volvo. They state that the proposed 1978 California system achieves sensor light-off in 30 seconds, compared to 20 seconds for the B21 application. The advanced approaches may allow the B27 to achieve sensor light-off as quickly as the B21, but the driveability implications of very short sensor light-off (and sensor cut-in) have not been fully explored by Volvo.

Volvo reported some data for the super-short configuration. The data involved keeping the sensor voltage setting constant at 50 MV, and varying "TV" and "Ist", neither of which were explained. TV is assumed to be a control system time constant, possibly the time delay between the time that the signal from the O_2 sensor passes through the set point value and the time that the fuel metering system begins to change the air/fuel ratio back toward stoichiometric. Ist is assumed to be a pressure value that possibly controls the warm up regulator. The best results were 0.15 HC, 4.02 CO, 0.24 NOx, 14.5 MPG_U with TV = 20 mm and Ist = 0.2. These results were obtained with a Degussa catalyst. Since the results were obtained with a catalyst that is not apparently Volvo's first choice, the results are hard to interpret. They do not appear to be as good as the low mileage results with the B21 application.

For future systems, Volvo plans to continue the use of the same fuel injection type that is on the current vehicles. This fuel injection type is the Bosch K-Jetronic or Continuous Injection System (CIS) system. Volvo previously used a Bosch electronic fuel injection system, the D-Jetronic, before the switch over to the mechanical, K-Jetronic system which Volvo feels offers advantages in cost, EGR tolerance, driveability, fuel economy, and servicing.

The K-Jetronic system cannot, by itself, provide the proper control of fuel metering required for successful 3-way catalyst operation, according to Volvo. They claim that the spread of air/fuel ratio variations is 40 times greater than is required. With the feedback control system, Volvo stated that except for the first 20 seconds of engine operation, their system will permit the 3-way catalyst to "operate continuously at a conversion efficiency of 90% or better for all three major pollutants."

Other Catalytic Systems

Volvo did not report any development or durability tests with 3-way catalyst plus oxidation catalysts or dual catalyst emission control systems.

Other Systems

Thermal Reactors

Volvo reported results from a thermal reactor program. Apparently, this program is targeted toward a non-catalytic "lean burn" approach. The project is being done with some assistance from Volvo Flygmotor, Volvo's aeronautical division. Volvo Flygmotor provided the thermal reactors and "combined swirl/squish", which is interpreted to mean a combustion chamber modification. With the thermal reactors, a modified intake manifold, 20 mm throttle valves, pulsair, and a lean choke, values of 0.4 HC, 4.5 CO, 2.7 NOx, 14 MPG_u were achieved. The vehicle description was not provided. By itself the swirl/squish yielded 1.3 HC, 11 CO, 2.8 NOx, 14 MPG_u. Work in this area continues.

Diesel Engines

Early in 1974, Volvo contracted with Ricardo & Company, Ltd. to design, develop and build 15 prototype Diesel engines for evaluation. Six engines are now installed in various Volvo vehicles, including their experimental taxicab for testing and in-house demonstration purposes. Volvo has no plans to produce this engine.

The engine is a 6-cylinder in-line 145 cubic inch Diesel. It has a Ricardo MK-V swirlchamber, and produces 70 hp at 4500 rpm and 98.4 lb ft of torque at 2400 rpm.

Volvo stated that they have contracted with VW for the development, production, and supply of Diesel engines for Volvo's 240 series of cars. This program will apparently be complete in late 1978 or early 1979.

Volvo stated that the introduction of Diesels for the U. S. market will depend on the NOx standard. According to Volvo, certification will not be possible or economically feasible below 1.5 grams per mile NOx.

Volvo also discussed the application of EGR to Diesels. Problems claimed were:

(1) At 1.0 NOx the fuel economy advantage over the gasoline engine is lost.
(2) EGR pipework must be much larger due to the unthrottled operation.
(3) Vacuum signals for EGR control do not exist. EGR control must use another parameter.

No data on Diesel vehicles equipped with EGR were provided.

Backup data or analysis for the Volvo claims could not be found in their status report. Because not one emission test of a Volvo/Ricardo or Volvo/VW Diesel vehicle was reported, Volvo must be making their claim based on information not reported to EPA. It is also curious that, although all emission data run by Volvo were requested by EPA, the Volvo/Ricardo 3-year program that resulted in 6 vehicles for test and demonstration programs has not yet produced one emission test.

Other Development Efforts

B27 Engine Improvements

Volvo is conducting an extensive program to reduce the engine-out emissions of the B27 engine. Work in the areas of (1) combustion chamber, (2) spark plug position, (3) inlet ports and manifold, and (4) camshaft have been conducted to investigate the effects of altered squish and swirl conditions. Volvo did not report any data resulting from this program, although "some potential for emissions reduction has been seen", according to Volvo.

From the extensive amount of what appears to be rather basic engine work being conducted by Volvo on the B27 engine, it appears that even though this is a relatively new engine (developed in conjunction with Peugeot and Renault), emissions control is being studied as an after-the-fact proposition, rather than being included in the original design of the engine. The development program could also be one targeted toward fuel economy improvements.

EGR Systems

The current B21 application does not use EGR. Since EGR is a well-known NOx reduction technique, it is logical to expect that some 3-way catalyst work would have been done by Volvo including EGR. Volvo did work in this area some time ago. Development problems with unreliable EGR systems and interactions between the EGR and the feedback systems slowed the development of the 3-way catalyst system so much that Volvo dropped the EGR in order to concentrate on the 3-way catalyst system. It should also be noted that Volvo does not need EGR to meet 1.5 NOx, the target for the 3-way catalyst B21 car in California. Because the performance of the B21/3-way catalyst system has been so good, Volvo is "most unwilling" to add EGR to this system. They predict losses in driveability, power output, and a 10% loss in fuel economy if they have to add EGR. According to Volvo this will be unsatisfactory from a customer standpoint and "could well force Volvo out of the U.S. market on fuel economy considerations."

Because of higher priority projects, Volvo is expending little effort in the area of EGR systems now. There would appear to be little need for Volvo to do so, if the NOx standard is 1.0 NOx or above.

7.3.17.2. Systems to be Used at Various Emissions Levels

Volvo provided the following table, labeled Table Volvo-8, as an indication of their system approaches toward future emission standards. Volvo's future systems are seen to be the major types, oxidation catalyst systems and 3-way catalyst systems. Volvo did not specifically indicate what systems would be targeted for the variety of possible emission standards considered in this report, so the following discussion contains primarily EPA estimates of the system choices.

1.5 HC, 15 CO, 2.0 NOx

Apparently, Volvo would stay with the current 1977 Federal systems, which consist of an oxidation catalyst, no air injection, and EGR. This basic system is also the same one that Volvo plans to use for the 1978 Federal vehicles, since Volvo is assuming that the standards will be set to be carryover from the 1977 Federal standards.

0.9 HC, 9 CO, 2.0 NOx

Volvo will need somewhat more than their current Federal systems at this level, since the B27 and B21 Federal durability cars line crossed for CO at 4K. Either the current California oxidation catalyst/air pump/EGR packages, or the pulsair/oxidation catalyst/EGR packages now under development would appear to be adequate. It should be pointed out, however, that Volvo stated in last year's status report that they favored 0.9 HC, 9 CO, 2.0 NOx as a level which might encourage Volvo to introduce the 3-way catalyst system.

0.41 HC, 9 CO, 1.5 NOx

Volvo would use the 3-way catalyst system at these levels. It is already in production for 1977 for California for the B21, and Volvo

Table Volvo-8

VOLVO EMISSION CONTROL SYSTEMS

	Engine Family	No Cyl Disp (in³)	Fuel System	Ignition	Catalyst	Air Injection	EGR System	Notes
1978 Federal	B21F	4 - 130	CI	Breakerless	Ox. PTX 514.5	-	Propl.	
	B27F	6 - 163	CI	Breakerless	Ox. PTX 514.5	-	Propl.	
1978 California	B21F	4 - 130	CI + λ-sond	Breakerless	3-way PTX 516	-	-	
	B27F	6 - 163	CI + λ-sond	Breakerless	3-way PTX 516	-	-	1st choice
	B27F	6 - 163	CI	Breakerless	Ox. PTX 516	Saginaw 85 $	Propl.	2nd choice
1979 Federal	B21F	4 - 130	CI	Breakerless	Ox. PTX	Pulsair	Propl.	Choice of systems depends on standards legislated for 1979.
	B27F	6 - 163	CI	Breakerless	Ox. PTX	Pulsair	Propl.	
	B21F	4 - 130	CI	Breakerless	Ox. PTX 516	Saginaw .65 $	Propl.	
	B27F	6 - 163	CI	Breakerless	Ox. PTX 516	Saginaw 85 $	Propl.	
	B21F	4 - 130	CI + λ-sond	Breakerless	3-way PTX 516	-	-	
	B27F	6 - 163	CI + λ-sond	Breakerless	3-way PTX 516	-	-	
1979 California	B21F	4 - 130	CI + λ-sond	Breakerless	3-way PTX 516	-	-	To meet*
	B27F	6 - 163	CI + λ-sond	Breakerless	3-way PTX 516	-	-	0.41/9/1.5

*1980 and later systems depend on standards established.

is trying to certify it for California at these standards for 1978 with the B27 engine. Backup oxidation catalyst systems are also under consideration.

0.41 HC, 3.4 CO, 2.0 NOx

Volvo would probably tend to prefer the 3-way catalyst approach at these levels, although they have not yet demonstrated the CO control needed at the 3.4 gm/mi level with a durability vehicle. It should also be noted that Volvo has already demonstrated control to this level with their 1977 California B27 durability vehicles, which are equipped with air injection, an oxidation catalyst, and EGR.

0.41 HC, 3.4 CO, 1.0 NOx

Without EGR, Volvo indicated that this level is about the maximum control that can be obtained from the 3-way catalyst system, especially for the B27 application. Volvo did not indicate any control systems other than the 3-way catalyst approach that would be considered at these levels.

0.41 HC, 3.4 CO, 0.4 NOx

Somewhat reluctantly, Volvo would attempt to add EGR to the 3-way catalyst system. Volvo indicated that this approach would result in driveability and fuel economy penalties.

7.3.17.3. Durability Testing Programs

Volvo has conducted, and is conducting, extensive durability tests of advanced emission control systems. Tests include investigation of catalyst durability, oxygen sensor durability, and vehicle/system durability.

Catalyst Durability Tests

Volvo reported catalyst durability results obtained from operating a vehicle on a dynamometer with periodic measurements of catalyst efficiency. The test is conducted for 1000 hours, with the vehicle operating on Volvo's "open road" driving cycle. The vehicle used was 3500 IW, equipped with Bosch K-Jetronic, feedback control, and various catalysts. The fuel contained no lead, no phosphorus, and less than 5 ppm sulfur. The catalysts tested are shown below, in Table Volvo-9.

Table Volvo-9

Catalysts Tested on 1000 Hr Test*

Catalyst Manufacturer	Designation	Substrate	Washcoat	Pt/Rh	Total Loading Troy Ounces
Engelhard	TWC-9B	300 cells per in^2	N.R.	19/1**	N.R.
Engelhard	TWC-16	Corning Ex20, 300 cells/in^2	N.R.	5/1**	0.096 (3 grams)
Engelhard	TWC-16	"	"	"	"
Degussa	OM 721	Corning Ex 20 "L" 2 Bed-300 cells /in^2		2/1	0.096 (3 grams)
Degussa	OM 721	"	"	5/1	"

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* Volvo Status Report, page 73-78

** Not specified. Value assumed by EPA based on other information.

Volvo did not report the exact description of the test used to measure conversion efficiency. It could be a simple catalyst efficiency test at some air-fuel ratio, or it could be the results of a 1975 FTP test.

The above limitations, coupled with the almost sterile fuel, make conclusions about the absolute level of performance of the various catalysts difficult. However, the results may be of some use in assessing the relative performance of the various catalysts. The results are shown on Table Volvo-10.

The results shown in Table Volvo-10 are somewhat difficult to interpret. The results are shown for two sets of two apparently identical catalysts. The two TWC-16 catalysts and the two Degussa catalysts are the same catalysts shown in Table Volvo-9. The differences in performance could be due to catalyst-to-catalyst variability, or to differences in feedback control system calibration, or to differences in oxygen sensors. Several different code number sensors were used. Volvo did not discuss the reasons for the differences in performance. If there is a reason due to calibration differences between the two TWC-16 catalysts, the first calibration would appear to be the most effective of the tested systems, yielding extrapolated 1000 hr catalyst efficiencies of over 80 per cent for all three pollutants.

Oxygen Sensor Durability

Current Volvo-suggested oxygen sensor maintenance (a change of the sensor) is scheduled for 15,000 mile intervals. In an attempt to investigate the impact of longer sensor change intervals, Volvo has conducted a program to run various sensors for extended mileages. Based on the results of the testing to date, Volvo states that "the prospects for increased oxygen sensor life are excellent." Some of Volvo's tests to 30,000 and 50,000 miles have shown good results, but until further production and field experience has been generated with this new technology Bosch, the oxygen sensor supplier, is not prepared to recommend an increase in the interval.

Table Volvo-10

Durability Performance
of Various 3-Way Catalysts

Catalyst	Efficiency at Zero Hours, per cent HC	CO	NOx	Efficiency at Extended Hours, per cent HC	CO	NOx	Comments
TWC-99	86	99	70	75	92	80	Full 1000 hours. Two sensor changes. NOx efficiency dropped to 61% at 600 hrs, a sensor change point, after which NOx efficiency improved. A lower setting at 1050 hours yielded efficiencies of 84, 98, and 75 per cent.
TWC-16	97	95	99	86	89	92	Results reported to 800 hours. Stable performance, with no sensor changes indicated.
TWC-16	95	99	81	76	73	78	Full 1000 hours. Two sensor changes reported. HC and CO performance steadily decreasing. NOx efficiency as low as 66% at 400 hours.
GM 721	93	100	84	86	80	78	Test stopped at 500 hours due to poor conversion. No sensor changes reported.
GM 721	97	98	99	92	88	78	Full 1000 hours. All efficiencies steadily decreasing. No sensor changes reported.

Current sensors can exceed 30,000 miles without mechanical problems, but exhaust deposits (unspecified) cause the signal to drift slightly, according to Volvo. Volvo did not specify what direction (rich or lean) the sensor shifted toward, but an examination of the Volvo results indicates that the sensors tend to shift rich.

Volvo reported results from the durability testing of 27 sensors. These sensors were tested on seven different vehicles. The sensors were tested for mileages ranging from 185 miles to 53,155 miles. Two sensors failed and three cracked.

Of the other sensors four are still running, and the others have been replaced or the test has stopped. Six sensors were labeled "rich" after the testing. Trends with mileage were not clear. Of the eleven sensors that had accumulated in excess of 30,000 miles, four were "ok", one was "rich", two had cracked, three are still running, and one had failed. The sensor tested for the longest period, 53,155 miles, was "ok".

Vehicle Durability Testing

Volvo is running test fleets of 3-way catalyst vehicles. The fleets are of two types, in-use and developmental.

U.S. Test Fleet

About one year ago, Volvo started a fleet of 25 3-way catalyst equipped vehicles on an in-use durability test. The vehicles are being driven primarily by Volvo employees, to simulate actual in-use driving. Volvo plans to run the sensors on these vehicles beyond 15,000 miles, except when a definite sensor problem shows up. The results to date from this testing are shown in Table Volvo-11.

Table Volvo-11

Emissions Results from "25-Car In-Use Fleet"*

Test Mileage	Number of Vehicles at This Mileage	Average Emissions HC	CO	NOx
0	25	0.21	2.71	0.13
10,000	18	0.31	3.50	0.42
20,000	7	0.34	3.92	0.63

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* Volvo Status Report, page 58.

Volvo did not report the individual vehicle test results or any information about sensor changes. Compared to the average in-use emissions of all the 1975 model year vehicles tested in EPA's emission factor program at the 10,000 mile point (1.38 HC, 23.7 CO, 2.47 NOx), the results are seen to be much better. Reductions of 75% for HC, 85% for CO, and 83% for NOx are implied. Volvo pointed out that the emissions at 20,000 miles were close to or above the statutory levels. According to Volvo, this confirms Volvo's assertion that real life emissions and deterioration factors exceed those obtained during certification testing.

The actual 20,000 mile test results from Volvo's durability car with 3-way catalyst system were 0.26 HC, 3.45 CO, 0.37 NOx. The results predicted from the DF least squares line for 20,000 miles are 0.25 HC, 3.71 CO, 0.39 NOx. Using the DF line results, Volvo's in-use experience suggests offsets (in-use compared to certification) of +26% for HC, +5% for CO, and +38% for NOx, at 20,000 miles. The differences may be due in part to the differences in maintenance. The Volvo certification vehicle had its oxygen sensor changed at 15,000 miles, whereas some of the in-use fleet may not have received a sensor replacement.

Developmental Test Fleets

Volvo reported developmental durability results on fifteen vehicles equipped with 3-way catalyst emission control systems. Of these fifteen, ten were equipped with the B21 engine and five were equipped with the B27 engine. The vehicle test results are shown on Table Volvo-12.

There are four types of durability schedules indicated on Table Volvo-12: EPA, Road, Tire, and Taxi. EPA is assumed to be the official AMA test used for EPA certification. Road is assumed to mean general in-use service. Tire is assumed to be a rapid mileage accumulation test, originally designed to test tires. Taxi is assumed to be taxicab use. Volvo did not report the test on which the fuel economy was measured. Fuel content was not specifically stated.

Volvo also reported test results from nine vehicles equipped with a B21 engine that were durability tested with catalysts of different Pt/Rh ratios. Two catalysts (F and G) at the 10/1 Pt/Rh ratio were tested. These catalysts differed in processing, according to Volvo. No details were provided. The third catalyst (H) has a 5/1 Pt/Rh ratio catalyst. Volvo ran vehicles on three test cycles: EPA, taxi, and tire. The vehicles were not specifically identified, so it cannot be said if these vehicles are in Table Volvo-12 or not. The 10/1 F and G catalysts could be TWC-9B and TWC-9D, and the 5/1 catalyst could be TWC-16. Table Volvo-13 lists the results at 50,000 miles and the computed DFs. The fuel used was stated to be 0.02 to 0.03 grams per gallon lead, more typical of the 1975 certification fuel than the lower lead levels found in use and in the current test fuel.

Table Volvo-12

Volvo Durability Vehicles*

Vehicle Identification	Type of Test	Catalyst	Mileage	HC	CO	NOx	MPG
Vehicles with B21 Engines							
JJT 448	Taxi	516/TWC-16	0	0.12	2.75	0.09	26.2
GGZ 769	Taxi	516/TWC-16	62,640	0.41	3.70	0.22	24.3
DDD 089	Tire	516/TWC-16	70,686	0.26	3.05	0.36	25.7
ABM 502	Tire	516/TWC-16	80,940	0.45	5.09	0.62	26.8
JPA 393	Taxi	516/TWC-21	0	0.22	4.06	0.12	26.8
DPF 536	Tire	516/TWC-98	50,137	0.12	3.74	1.29	27.1
BOC 530	Road	516/TWC-98	62,180	0.48	4.62	0.78	26.2
HGB 550	Taxi	516/TWC-98	77,226	0.43	6.79	1.26	26.9
DPF 536	Tire	514.5/TWC-98	26,394	0.30	3.38	0.57	27.7
JJB 961	EPA	514.5/TWC-98	45,071	0.43	5.26	1.31	26.7
Vehicles with B27 Engines							
BJL 545	Tire	Degussa TWC	30,000	0.69	6.20	0.36	15.2
JJB 561	EPA	516/TWC-16	10,000	0.27	5.58	1.32	15.1
BJL 545	Tire	516/TWC-16	25,000	0.38	3.46	0.38	15.1
JGY 272	EPA	516/TWC-16	45,000	0.64	5.40	0.36	15.1
MMB 059	EPA	516/TWC-16	50,086	0.41	6.49	1.30	14.8

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* Volvo Status Report, page 29, page 60.

Table Volvo-13

50,000 Mile Results and Deterioration Factors*

Test	Catalyst (Pt/Rh)	50,000 Mile Emissions HC	50,000 Mile Emissions CO	50,000 Mile Emissions NOx	Deterioration Factors HC	Deterioration Factors CO	Deterioration Factors NOx
EPA	F (19/1)	0.52	2.56	1.01	1.76	1.19	4.27
EPA	G (19/1)	0.39	3.23	1.09	2.10	1.20	4.70
EPA	H (5/1)	0.23	5.04	0.51	1.69	1.65	2.56
Taxi	F (19/1)	1.37	10.9	1.98	5.51	3.95	1.65
Taxi	G (19/1	0.45	6.42	1.10	0.84	0.67	2.41
Taxi	H (5/1)	0.18	2.26	0.69	0.72	0.68	3.56
Tire	G (19/1)	0.32	3.74	1.30	1.79	1.05	4.06
Tire	H (5/1)	0.21	3.45	0.26	0.72	0.74	6.30
Tire	H (5/1)	0.38	3.42	0.28	1.50	1.36	1.93

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* Volvo Status Report, page 4.

The results shown on Table Volvo-13 must be interpreted in light of the fuel lead level. As far as catalyst poisoning goes, Engelhard stated that there was more poison effect on a catalyst at 5,000 miles with the 1975 type fuel than there was on a 25,000 mile catalyst using the 1977 type fuel. It may be stretching a point to conclude that the Volvo 50,000 mile results shown in Table Volvo-13 are equivalent to 250,000 miles of operation, because thermal aging effects are not accounted for, but it is probably appropriate to conclude that the 50,000 mile results would be significantly better than those shown if lower lead levels were used. Table Volvo-13 also can be interpreted to support the superiority of the 5/1 catalyst, especially for HC and NOx control at 50,000 miles.

An examination of the Volvo data for which there were both base engine and tailpipe emissions reported can be used to compare the TWC-16 and the TWC-9B (5/1 Pt/Rh ratio and 19/1 Pt/Rh ratio catalysts, respectively). High mileage (50,000 or greater) efficiencies for HC, CO, and NOx are shown for the two catalysts in Table Volvo-14.

Table Volvo-14

High Mileage 1975 FTP Cold Start Conversion Efficiencies of Two Pt/Rh Ratio Catalysts

Catalyst	HC	CO	NOx
TWC-9B (19/1)	78%	82%	65%
TWC-9B (19/1)	64%	57%	71%
average	71%	70%	68%
TWC-16 (5/1)	80%	82%	75%
TWC-16 (5/1)	83%	80%	91%
TWC-16 (5/1)	74%	79%	92%
average	79%	80%	86%

The low and high mileage base engine levels are shown in Table Volvo-15. All the vehicles used the B21 engine.

Table Volvo-15

Base Engine Values

Mileage	Vehicles	HC	CO	NOx
Low	GEC 769	1.55	18.1	3.51
Low	HLH 550	1.36	13.4	3.02
Low	DOD 889	1.28	18.5	2.89
Low	DPF 536	1.43	17.9	3.29
Low	ANM 502	1.54	18.1	3.65
Average	-	1.43	17.2	3.27
High	GEC 769	0.96	12.69	2.81
High	HLH 550	1.22	14.03	3.28
High	DOD 889	1.27	17.46	2.83
High	DPF 536	1.45	20.79	3.67
High	ANM 502	1.46	16.64	3.63
Average	-	1.27	16.32	3.24

The base engine emissions did not change greatly during mileage accumulation.

Volvo's durability program is an example of an experimental program apparently designed to get information quickly on a variety of subjects. Compromises have apparently been made in terms of of determining precisely what the performance of the advanced systems will be on official EPA durability. The cycles run in most cases were not AMA durability, possibly because of time constraints (a tire test could be expected to put more miles on a vehicle in a given amount of time, compared to AMA schedule) or desire to get experience on a different duty cycle (the Taxi test vehicles). Additionally, many sensor changes were made, possibly in an attempt to evaluate different sensors and sensor durability. Finally, the lead level in the fuel actually used for the vehicles reported was not precisely specified by Volvo. Some vehicles were apparently run on 0.02 to 0.03 gpg fuel, and the catalyst efficiency slave vehicle was apparently run on sterile fuel. In last year's status report, Volvo reported that in January 1975, the fuel was changed from 0.02-0.026 gpg to 2 to 5 ppm. It is assumed that all vehicle test data reported by Volvo in this year's report were run on the lower lead content fuel, except for the results shown on Table Volvo-13.

Because of the above differences between the durability test program that Volvo ran and the official certification test that is used to determine compliance with the standards, the results have to be interpreted carefully.

7.3.17.4 Progress and Problems

Volvo has maintained their position of being one of the leaders in the 3-way catalyst development field. They are the first manufacturer to have introduced such a system into commercial use, for the 1977 model year on the California vehicles equipped with the B21 engine. Volvo also plans to try to introduce the 3-way catalyst system for the B27 application for California for the 1978 model year.

Volvo is also the manufacturer that has come the closest to certifying a vehicle at the statutory emission standards. Their performance with the B21 California application has been the best reported to date.

Volvo's biggest emission control problem is with CO at the 3.4 gm/mi level. Volvo feels that driveability compromises may have to be made to control CO to the 3.4 CO level. Generally, there has been no difficulty in attaining the CO control needed for the 9 CO level. Another major area of difficulty for Volvo has been the adaptation of the 3-way catalyst system to the B27 engine, due to both the engine's basic emission levels and its configuration. Regarding CO control, Volvo did not report further work on either the quick chokes with cold-start acceleration enrichment approach or the heated injector approach which were previously reported to EPA.

Because of their concentration on non-EGR systems, Volvo may have slipped behind other manufacturers in the EGR area. Other manufacturers are exploring the use of electronically controlled EGR systems, for example. Below NOx levels of 1.0, Volvo feels that they would need to incorporate EGR into their system.

No emission results were reported for vehicles lighter in weight than current models. Volvo's current sales-weighted composite fuel economy is about 20 mpg, which is probably less than the requirements for the 1981-1984 time period. It is known that Volvo has a lighter weight vehicle in Europe, due to their takeover of DAF, but no emission results were reported for such a vehicle. It may be that the development time to adapt that vehicle to meet the U.S. standards is significantly less than three years.

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WASHINGTON, D.C. 20460

Dear

As part of its continuing overview of the industry's efforts, and to implement sections 202(b)(4) and 202(b)(5) of the Clean Air Act, as amended, the Environmental Protection Agency needs current information on efforts by automobile manufacturers to meet the 1978 and 1979 and subsequent model year light duty motor vehicle emission standards. Accordingly, pursuant to section 307(a)(1) of the Clean Air Act, you are requested to provide information regarding your development status and progress toward meeting these standards. This information is similar to and will update the information which your company has provided in the past in response to similar requests.

The desired information, which is described in the enclosed outline, is divided into five main areas: a) information describing the design of your emission control systems, b) information describing your test and development programs, c) emission data covering both regulated and non-regulated pollutants, d) fuel economy, and e) cost information. Additionally, any specific questions that may be relevant only to your company are attached to the enclosed outline.

In previous years some submissions have been incomplete with respect to information regarding programs and systems identified as primarily concerned with fuel economy. I understand that the rationale behind this was that these systems were related only to fuel economy and had no significance for emissions. This rationale implies that emissions and fuel economy are unrelated, which conflicts with previous statements made by the industry that fuel economy and emissions are related. On this basis, I request that your submission include complete coverage of all fuel economy related programs and developments. This will allow my staff to analyse this information, and determine the degree to which emissions are affected.

The Agency is becoming increasingly aware of the important role that driveability plays in the emissions performance of vehicles in customer use. It is suspected that unfavorable driveability characteristics may increase the likelihood that a vehicle will be maladjusted in an attempt to improve driveability. It is requested, therefore, that your submission provide complete information on the driveability characteristics of current and developmental emission control systems. The Agency should also be provided with a complete account of all systems that are intended to improve or influence driveability.

The information provided by your company should, in general, follow the enclosed outline. You may limit the information supplied in response to this request to that information which has not previously been supplied to EPA. However, if portions of the desired information have already been supplied to EPA and you wish not to resubmit these materials, please indicate the appropriate documents by specific reference.

Three copies of your response should be submitted to EPA no later than December 15, 1976. Responses should be addressed to:

Director, Emission Control Technology Division
Attention: Status Report Team
Motor Vehicle Emission Laboratory
2565 Plymouth Road
Ann Arbor, Michigan 48105, USA

We realize that much of the information requested on the 1978 model year systems may be included in your company's 1978 Part I certification application. That document, however, is needed by the Certification Branch, and cannot be made as available to the Status Report Team as is necessary for the purpose of this report. Therefore, if you choose to reference the Part I in your submission, include two copies of that document with your response to this letter, in addition to the other information requested in the outline.

Questions concerning the data requested should be addressed to Mr. John DeKany, Director of the Emission Control Technology Division, whose group has primary responsibility within EPA for acquiring, analysing, and reporting data on the status of technology for automotive emission control. Also, staff from that Division may contact you for additional information or explanations, and such requests should be considered by you to be an integral part of the request for data made by this letter.

Your cooperation in ensuring that the Environmental Protection Agency receives clear, detailed, and understandable information describing the efforts of your company in the design, development and testing of 1978, 1979 and subsequent model year emission control systems will contributes materially to assuring a sound decision making process related to the implementation of the Clean Air Act.

Sincerely yours,

Roger Strelow
Assistant Administrator
for Air and Waste Management

OUTLINE FOR EMISSION CONTROL STATUS REPORT

The following outline should be followed in submitting the requested information. Any information not identified in the outline or the discussion of the outline that you feel is necessary for an accurate and complete description of the emission control technical effort of your company may also be included.

Since the legislated emission standards for 1978 are .41 HC, 3.4 CO, 0.4 NOx, this scenario should be fully discussed. Because of Congressional interest in modifying the emission standards for future model years, the House-Senate Conference Committee Report scenario should also be discussed. The Conference Committee Report reflects the most current Congressional considerations for near-term modification of the Clean Air Act. Each emission standard of the Conference Committee Report, which is as follows, should be discussed separately:

Model Year	HC	CO	NOx
1978	1.5	15	2.0
1979, 1980	.41	3.4	2.0
1981	.41	3.4	1.0

I. Emission Control Systems

- A. Identification and description of the entire emission control system
- B. Discussion of system optimization
- C. Description of system operation

II. Development and Testing Program

- A. Description of test program and organization
- B. Test program basis and rationale
- C. Test vehicle description
- D. Test program status

III. Experimental Data

- A. Vehicle data
- B. Non-vehicle data

IV. Fuel Economy

- A. On the 1975 test procedure ("city" cycle) and on the EPA non-metropolitan ("highway") cycle
- B. Fuel economy on other cycles

V. Cost Information

- A. First cost
- B. Operating cost

VI. Confidentiality of Trade Secret Information

Discussion of Outline

I. EMISSION CONTROL SYSTEMS

The Agency needs information on all systems that either directly or indirectly influence emission control. As explained in the accompanying letter, systems that affect fuel economy and driveability may significantly influence emission control. Accordingly you are requested to provide the information discussed below for all systems and components that have been or are now being developed for the purpose of improving emissions, fuel economy or driveability.

A. Identification and Description of the Engine Emission Control System

This should include both a generic and specific description of each system (first choice and all backup systems) under consideration for the model years under discussion. If any feature of the emission control system differs between model lines it should be treated as a different system. An example might be the emission control system for a 2000lb. IW vehicle as contrasted to the emission control system for a 5000 lb. IW vehicle. An example of a generic model year 1977 emission control system is engine modification, EGR, and an oxidation catalyst. The detailed description should include enough information about the system to distinguish it from other systems in the same generic category. The description should be accompanied by engineering drawings and pictures when appropriate to more fully identify and describe the system or subsystem. At least the following topics should be discussed and fully identified.

1. Engine type - reciprocating 4-stroke, rotary, etc.

2. Engine modifications - compression ratio, combustion chamber shape, valve timing, bore/stroke ratio, spark plug location, etc.

3. Intake system - detailed description of carburetor(s), fuel injection system, choke and choke control, intake manifold and intake port.

4. Exhaust port and manifold description.

5. Ignition system - spark advance as a function of all spark control parameters.

6. EGR system - flow rate as a function of engine speed and load, type of control, take-off location, introduction location, type of cooling (if cooled).

7. Air injection - type of pump, supplier, flow rate vs. engine speed and load, modulation and switching control, location and type of air injection nozzles.

8. Thermal reactor - type (lean/rich), configuration, materials, internal flow geometry.

9. Catalysts - type (reducing, oxidizing, three-way), active material (general) class, loading and total weight of each catalyst material and the total in troy ounces per vehicle, substrate structure type (monolith/pellet), substrate composition, washcoat composition, total surface area of the washcoat, surface area per displacement of the washcoat, catalyst location, shape and size, geometry, manufacturer and manufacturer's identification number, nominal space velocity and space velocity range.

10. Evaporative emission control system - general description including degree of use of air cleaner/horn as storage volume, type of storage material, volume of storage materials,purge and fill tube routing, purge rate, purge controls, and location and design of purge vapor inlet to the air cleaner/carburetor/exhaust system.

B. Discussion of System Optimization

1. This should include a discussion of the design constraints within which each system was optimized for emissions. Examples of such constraints are fuel economy, safety, cost, driveability, packaging, maintenance, and performance. Quantitative values should be identified for all of the constraints for which your company has determined such quantitative values. Others should be discussed in the manner in which they were set down for the design engineer.

2. This should provide a discussion of all designs that were not successful in surviving the optimization studies that your company performed, giving the criteria by which they failed.

3. Of the systems that are under consideration for the model year being discussed, identify and explain the trade-offs that have been made within the emission control system. Trade-offs to be considered are first costs, operating costs, fuel economy, emission levels, driveability, performance, and durability. The rationale considered in evaluating these trade-offs shall be described and explained. Quantify any examples

by including design calculations or engineering reports. An example might be catalyst location, where one emission control related trade-off could be the trade-off between a location close to the exhaust port for fast light off vs. a more remote location that might provide a longer catalyst life. Another trade-off might be the interaction between increased mechanical octane (to permit operation on 91 RON fuel at higher compression ratio, for improved fuel economy) and the desire to reduce engine-out HC emissions.

4. The Agency considers that there are two primary areas in which the design and/or operation of the emission control system might influence vehicle safety. These areas refer to fuel system/evaporative emission control design and/or operation and catalyst temperature. To assist the Agency to understand the emissions/safety interrelationships, please answer the following questions.

a. At what stage in the research, design, development and testing phase are the safety aspects of emission control systems and/or devices considered?

b. What sort of testing and analysis is performed to evaluate the designs for their likely safety-related performance? Please give specific examples.

c. List and discuss all changes made to the exhaust and evaporative emission control systems developed by your company that were made because of safety considerations. Include both changes made during the development process and changes made after the systems were in production.

5. The discussion of system optimization should also include discussion of evaporative emission control, with special emphasis on the interactions between the evaporative and exhaust emission control system. The Agency knows that there can be interactions between the evaporative and exhaust emission control systems, and considers the subject area to be a more important one for the future, especially at low HC and CO levels with more effective evaporative emission control systems. More effective evaporative emission control systems may be required for the 1978 EPA 6 gram SHED standard. Therefore, you are requested to discuss the optimization of the entire emission control system, including the evaporative emission control system. The discussion shall include listing of all test results, including all SHED tests run on your vehicles with developmental emission control systems.

6. Discuss any trade-offs or emission control system modifications that may have been made to improve sulfuric acid or hydrogen cyanide emissions.

C. Description of System Operation

1. The sequence of operations of the entire emission control system during the 1975 Federal Test Procedure should be discussed in detail, with special attention given to those parameters which vary during the cycle, for example, spark timing, the choke position, air injection (if modulated or switched), EGR flow rate, and evaporative system purge.

As backup information to the general description of how the emission control system works during the emission test, please provide the following quantitative information as a function of time during the 1975 CVS-CH test, starting with "key-on".

a. engine exhaust flow rate in SCFM

b. engine air flow rate in SCFM

c. spark timing-vacuum and centrifugal separately, plus total spark timing or simply total spark timing if an electronic system is used.

d. exhaust gas recirculation rate as a percentage of fresh inlet air flow.

e. air injection flow rate into the exhaust manifold or pipe.

f. nominal engine air/fuel ratio, as determined upstream of any aftertreatment device, for example a catalyst or thermal reactor.

g. exhaust gas temperature before and after any aftertreatment device.

h. catalyst temperature (if a catalyst is used). The information may be presented graphically, for example, superimposed on the speed vs. time trace of the emission test, or in tabular form, on a second-by-second basis.

i. exhaust gas O_2 level before and after any aftertreatment device.

j. evaporative system condition and purge rate.

The above information is requested for each engine family/emission control system. If more than one control system behaves the same during the test, that may be noted and not detailed. However, control systems with markedly different characteristics; i.e., proportional vs. non-proportional EGR or different carburetor metering principles, should not be deleted.

2. The way in which the system operates under the following other conditions should be discussed; the emissions under such conditions should be quantified in III-A below.

a. Operation in low (less than 60 degrees F) or high (greater than 86 degrees F) temperature ambient conditions.

b. Operation under conditions of speed and/or load which do not occur during the 1975 Federal Test Procedure.

c. Operation at low barometric pressure, for example, at elevations significantly higher than sea level.

II. DEVELOPMENT AND TESTING PROGRAM

A. Description of Test Programs

1. This should include a general description of the type of laboratory or bench scale testing carried out on emission control subsystems or components.

2. This should include a description of any catalyst screening tests and the basis for selecting/rejecting catalysts.

3. This should include a discussion of any tests made for optimization purposes described in I-B above, a general description of the variables that were changed, the range over which they were varied, and the inferences drawn from the system of optimization tests.

B. Test Program Basis and Rationale

1. This should include general discussion of the use of vehicles for component testing and trade-offs studies, especially as it affects system optimization. Distinction should be made between vehicles used for component testing vs. complete system tests.

2. This should include a complete description of all vehicle emission test programs for the model year under discussion, including the number and type of vehicles, the reasons for choosing the vehicle mix, the mileage accumulation schedule for each vehicle and the number of emission tests at each mileage point.

C. Test Vehicle Description

This should include an identification of the vehicle; car line, test weight, transmission type, axle ratio and an identification of the emission control system as outlined in I-A.

D. Test Program Status

This should include a discussion of the current status of each emission durability vehicle and a comparison of its status with respect to the original planning. Significant problem areas, if they exist, should be identified.

III. EXPERIMENTAL DATA

A. Vehicle Data

1. Include 1975 FTP data on all durability fleet vehicles described in II-B above.

2. Include a description of the reasons for any vehicle not completing the full scheduled durability mileage.

3. Include a discussion of the driveability and performance of the test vehicle, again with quantitative data and with quantitative comparisons to current model year vehicles. Please include the driveability rating procedure used by your company if this has not previously been supplied.

B. Non-Vehicle Data

1. This should include the results from any catalyst screening tests, with a description of test methodology, and must include the test results from the catalysts that were selected for the durability vehicles.

2. Include any other non-vehicle data considered important, such as engine dynamometer studies of the effect of fuel contaminants on catalyst durability.

C. Unregulated Pollutant Emissions

All data developed by your company on the emissions of sulfuric acid, hydrogen cyanide, platinum, other particulates, and other unregulated pollutants emitted from future emission control systems, and from current vehicles, should be presented. This includes all data from bench, engine dynamometer and vehicle tests.

A full description of the measurement methods (driving schedule, sampling and analytical techniques) used to obtain the above information should be provided.

IV. FUEL ECONOMY

A. On the 1975 Test Procedure

Provide the weighted 1975 fuel economy for all tests run on advanced emission control systems. Use the following formulas for fuel economy and fuel consumption:

$$\text{fuel economy in miles per gallon} = \frac{2421}{.866\ HC + .429\ CO + .273\ CO_2}$$

Where HC, CO and CO_2 are the weighted exhaust constituents in grams per mile for the entire 1975 test, with the same .43/.57 cold start/hot start weighting as applied to the HC and CO values for the 1975 test also applied to the CO_2 values.

$$\text{fuel consumption in litres per 100 kilometres} = \frac{235.2}{mpg}$$

B. On the EPA Non-metropolitan Driving Cycle

Provide the fuel economy and fuel consumption data for all tests run using the EPA Non-metropolitan ("Highway") Driving Cycle. Use the formulas in IV-A, above except that the HC, CO and CO_2 values in grams per mile are, of course, not weighted.

C. Fuel Economy on Other Cycles

If you possess fuel economy data using a different procedure, you may also submit that data. The test procedures should be referenced or specified in detail, if that information has not been previously submitted to EPA.

V. COST INFORMATION

A. First Cost

1. The cost breakdown should be in the same form as that used by the National Academy of Sciences Committee on Motor Vehicle Emissions in Table 5-2 of their February 15, 1973 report to the EPA.

This should also be specific as to what fraction of the various product lines will require specific devices.

B. Operating Costs

This should include expected extra costs to the customer over the vehicle lifetime (assume 50,000 miles) due to:

1. Fuel and lubricant cost, specifying the miles per gallon fuel economy assumed for each engine family and a comparison to 1973 model year vehicles of the same class.

2. Maintenance cost other than catalyst replacement. Such estimate should break out parts of labor cost separately, providing the ratios of parts cost for OEM vs. replacement cost. The estimate should also indicate the expected level of required maintenance on each major emission control component which results in such costs.

3. Catalyst replacement cost. This estimate should separate labor and material costs and should give the estimated life of the catalyst. Material costs should break out catalyst and container costs.

VI. CONFIDENTIALITY OF TRADE SECRET INFORMATION

A. Information submitted in response to the request which accompanied this outline will be deemed to have been obtained pursuant to section 307(a)(1) of the Clean Air Act.

B. This means that only information which"...would divulge trade secrets or secret processes" will be kept in confidence. (Even this information will not be kept confidential in two situations: (1) when the information is emission data, or (2) if and when the information becomes relevant to any proceeding under the Act. See, in particular, paragraph D.) In order to assure that such information will be kept confidential prior to any such proceeding, you must 1) put the information on separate pages in the report that are clearly marked "CONFIDENTIAL" and are easily detached from the report and 2) in a separate section of the report labeled "CONFIDENTIAL INFORMATION" identify the number of each page on which confidential data appear and provide in that section the information to substantiate your claim for confidentiality. If such claims for confidentiality and supporting information are not provided at the time of submission of your response to this inquiry, all claims of confidentiality will be deemed to have been waived.

C. If the Administrator determines that a satisfactory showing has not been made that the information would disclose trade secrets or secret processes, you will be notified by certified mail. No sooner than 30 days following the mailing of such notice, any information with respect to which trade secret status has not been established will be placed in a public docket. Any information as to which the Administrator determines that a satisfactory showing has been made will be held confidential in the period prior to commencement of any suspension proceeding.

D. As in the case of the previous suspension proceeding, if any trade secret information becomes pertinent to the issues raised in a new proceeding on an application for suspension, it may be disclosed by the Administrator. In order to retain confidential treatment of such information you must show to the satisfaction of the Administrator, that non-disclosure of such information is justified by "...exceptional considerations",* as that phrase was defined in the course of the previous suspension proceeding. The showing that must be made is that the information is of such slight probative value in resolving the issue being considered by comparison to the harm likely to result from disclosure that public release of the information is not justified. If the Administrator determines that a satisfactory showing has not been made, you will be notified by certified mail. No sooner than 10 days following the mailing of such notice and telephone notice to a representative of your General Counsel's office, such information will be placed in a public docket. Any information as to which the Administrator determines that a satisfactory showing has been made will be held confidential and will not be considered by the Administrator in deciding whether to grant or deny a pending application for suspension.

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* December 3, 1974 39 FR 233 P. 41899

Table A1-1

Date of Receipt of Status Reports
from the Various Manufacturers

(Requested Dates: December 15, 1976 for
all manufacturers except MECA members
which were due January 3, 1977)

Date	Reports Received from	Comments
December 10, 1976	Mitsubishi	Early, incomplete status report
December 14, 1976	Chrysler	Early
December 15, 1976	Holley	On time
	Bendix	
December 16, 1976	GM	1 day late
	Questor	
	Ford	Incomplete Status Report
	Toyota	Incomplete Status Report
December 17, 1976	Ethyl	Two days late
	Rolls Royce	
December 20, 1976	Nissan	Five days late
	Honda	
	AMC	Part I only
December 21, 1976	AMC	Six days late
	Ford	Status Report completed
	Mitsubishi	Cal. information for Status Report
December 27, 1976	Toyo Kogyo	Twelve days late
	Citroën	
	Toyota	Status Report received
December 29, 1976	Volvo	Fourteen days late
December 30, 1976	Fiat	Fifteen days late
January 3, 1977	VW	Nineteen days late
	Peugeot	
	Renault	
January 10, 1977	Walker*	Seven days late

January 12, 1977	Engelhard	Twenty-eight days late
January 18, 1977	Matthey Bishop*	Fifteen days late
January 20, 1977	Dresser	Thirty-six days late
January 21, 1977	Bosch	Thirty-seven days late
January 24, 1977	Saab BMW	Forty days late
February 4, 1977	Fuji	Fifty-one days late
February 8, 1977	Mercedes-Benz	Fifty-five days late
February 22, 1977	British Leyland	Sixty-nine days late
February 28, 1977	U.O.P.*	Fifty-six days late
"	Gould	Never received

* MECA Member